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CHARACTERIZATION OF THE ACTIVATED SLUDGE PROCESS

Robert D. Bargman, et al

Los Angeles City Bureau of Sanitation

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April 1973

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Characterization of the Activated Sludge Process

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CHARACTERIZATION OF THE ACTIVATED SLUDGE PROCESS

by

Robert D. Bargman
Joseph Borgerding
Bureau of Sanitation
City of Los Angeles
Los Angeles, California 90012

Contract #14-12-148
Project 17090 FJU

Project Officer

Robert Smith
U.S. Environmental Protection Agency
National Environmental Research Center
Cincinnati, Ohio 45268

Prepared for

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ABSTRACT

Operational control parameters of the activated sludge process during steady-state and transient flow conditions were evaluated and related to carbon, nitrogen, and phosphorus removals.

During steady-state testing, chemical oxygen demand to mixed liquor volatile solids ratio, net growth rate, aeration tank detention time, and final settling tank detention time were found to be the key operational control parameters. Changes in COD removal and suspended solids removal were found to be proportional to a change in control parameter. Nitrogen removal was related to specific operational parameters and system nitrogen balances were computed. Phosphorus removal without external chemical addition was related to specific operational parameters.

This report was submitted in fulfillment of Contract #14-12-148, under the sponsorship of the Environmental Protection Agency by the City of Los Angeles, Bureau of Sanitation, Los Angeles, California.

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I

CONCLUSIONS

On March 21, 1968, the City of Los Angeles contracted with the Federal Water Pollution Control Administration to study the activated sludge process at the Hyperion Treatment Plant in Los Angeles.

The objectives of the study program were:

1. To develop a set of data which defined average 24-hour performance of carbon, nitrogen, and phosphorus removal as a function of treatment plant operation for a non-diurnal (constant) flow.

2. The study of the time-dependent behavior of carbon, nitrogen, and phosphorus removal as a function of treatment plant operation for diurnal flow.

3. Use of the data from the outlined objectives for validation of a computer program devised by Robert Smith of the Cincinnati Water Research Laboratory.

The computer model is an attempt to bring together, in one computational scheme, the significant cost and performance relationships for the group of individual processes which compose the activated sludge process. In order to make this program operational, many assumptions had to be made concerning points not thoroughly researched in the past. The critical need for validation of assumptions led to the inception of this study contract, and use of Hyperion Treatment Plant as a source of data.

An extensive study program was initiated, from which the necessary data was gathered to fulfill the objectives as outlined above. The first phase of data collection began on September 10, 1968, and lasted until April 15, 1969. During this time, numerous chemical and physical tests were made during different operational modes of the activated sludge process while treating a constant volume waste stream.

A direct relation was established between COD and BOD removal and plant operation. Total carbon in the waste stream could not be measured directly, so indicators such as biochemical oxygen demand and chemical oxygen demand were used to quantitatively indicate the carbonaceous compounds. Some correlation was found between COD and BOD and total organic carbon measurements.

Nitrogen removal was not accomplished during the study period. An analysis of the data showed that the activated sludge process will not remove nitrogen from the waste stream under the operational conditions tested. Nitrogen balances for each flow stream within the activated sludge process were computed.

Phosphorous removals were obtained under certain operational conditions of the activated sludge process. These phosphorus removals were unique in that no chemical pre-treatment was necessary to achieve phosphorus removals of up to 96%.

The effect of applied substrate (TOC, COD, or BOD) on the rate of synthesis of heterotrophs was studied. It was found that the rate of application of substrate carbon has a direct relation with the mass of new cells produced in the activated sludge process. It was also found that this relation may be used to predict or control the activated sludge process.

The second phase of data collection lasted from June 30, 1969, to July 11, 1969. During this period, continuous testing and recording devices were used to measure carbon, nitrogen and phosphorus levels. The transient behavior of carbon, nitrogen, and phosphorus streams was shown, but is difficult to correlate due to limitations in the recording instruments and process equipment.

II

RECOMMENDATIONS FOR FUTURE WORK

The results of Phase I and Phase II have been summarized and the data analyzed. In retrospect, it is felt that there are several areas in which further studies should be pursued.

Nitrification was attempted throughout Phase I, but never accomplished. Enough time should be given in the future to study in depth all the operating conditions which have an effect on nitrification. This could be effected by studying:

1. air rates
2. substrate loadings
3. detention times
4. net growth rates
5. final settler detention times
6. interrelated effects on the above

Phosphate removal was accomplished during Phase I, but the removal mechanism never explicitly defined. A more intensive study of pH, air rates, and chemical analyses should be undertaken in order to accurately define the phosphate removal mechanism.

Phase II should be continued. Due to the difficulties and lack of time encountered, steady-state conditions were never met. The data gathered indicated certain trends, but not enough data was gathered to show conclusively the ability of the activated sludge process to produce a consistent quality of effluent with major fluctuations in influent quality.

In addition, the question as to the relative efficiencies of plug flow and completely mixed aerators is still open. In both phases of testing at Hyperion, it was assumed that the aeration tanks were of the plug flow pattern. In future studies, a plug flow tank should actually be simulated and its removal characteristics compared to those of the long, narrow aeration tank currently in use.

III

BACKGROUND

Theory

Activated sludge is formed by aerating the soluble and suspended wastes in the presence of bacteria until the bacteria have stabilized the organic matter present. Stabilization and removal of carbon, nitrogen and phosphorus compounds is accomplished through the kinetics of biological synthesis. Control of this process is accomplished by controlling the growth phase of the bacteria. The growth phase of bacteria, or rate of synthesis, can be conveniently divided into different phases. They are:

1. log growth phase
2. declining growth phase
3. endogenous phase

Each phase corresponds to a different food-microorganism ratio, which in turn controls the flocculant character of the sludge.

Other factors which influence the efficiency of the activated sludge process are temperature, dissolved oxygen, pH, and nutritional requirements of the bacteria.

Control Parameters

Control of the activated sludge process for satisfactory effluent quality is accomplished by dictating the environmental conditions and number of bacteria in the system. Parameters used to express environmental conditions in the aeration tank are 1) air flow to sewage flow ratio; 2) mixed liquor dissolved oxygen level; 3) mixed liquor pH; 4) aeration tank temperature; 5) aeration tank detention time; 6) substrate to aeration tank volume ratio; and 7) substrate to cell concentration ratio.

The first two parameters, air to sewage ratio and dissolved oxygen concentration are dependent. A change in air to sewage ratio will be followed by a change in dissolved oxygen. The concentration of dissolved oxygen is critical, as every activated sludge system will have a minimum level, below which, poor treatment will result. It follows that dissolved oxygen concentration could be used as a control for blower output.

In most activated sludge plants treating domestic waste, aeration tank pH needs no control. However, systems treating industrial wastes could require pH control of the sewage before entering activated sludge treatment.

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Aeration tank temperature is not easily controlled. It is unfortunate, as a drop in temperature causes a drop in cell activity. Thus, efforts to obtain a high-quality effluent in winter months are hampered by low temperature.

Detention time in the aeration tanks is not controllable in most treatment plants. Today, many plants are being constructed upstream of the original discharge points. These plants are being constructed to draw off a constant flow from a trunk sewer. In these plants, detention time could be changed by varying the number of aeration tanks in use or varying the influent pumping rate. In general, changes in effluent quality unless the system is already operating at a critical detention time.

The substrate loading to aeration tank volume ratio can be used as a control parameter, but is not sensitive enough as large changes in this ratio usually do not result in large changes in effluent quality.

The substrate loading to aeration tank cell concentration ratio is the key parameter to control of the activated sludge process as it relates biological activity to substrate loading. Changes in this parameter can be quantitatively linked to changes in effluent quality.

The final settling control parameters are of secondary importance in controlling the activated sludge process. Overflow rates which are too high, tanks with short circuiting patterns, and undersized return sludge pumps may cause final settling to become a controlling factor. Normally it is not.

Applications

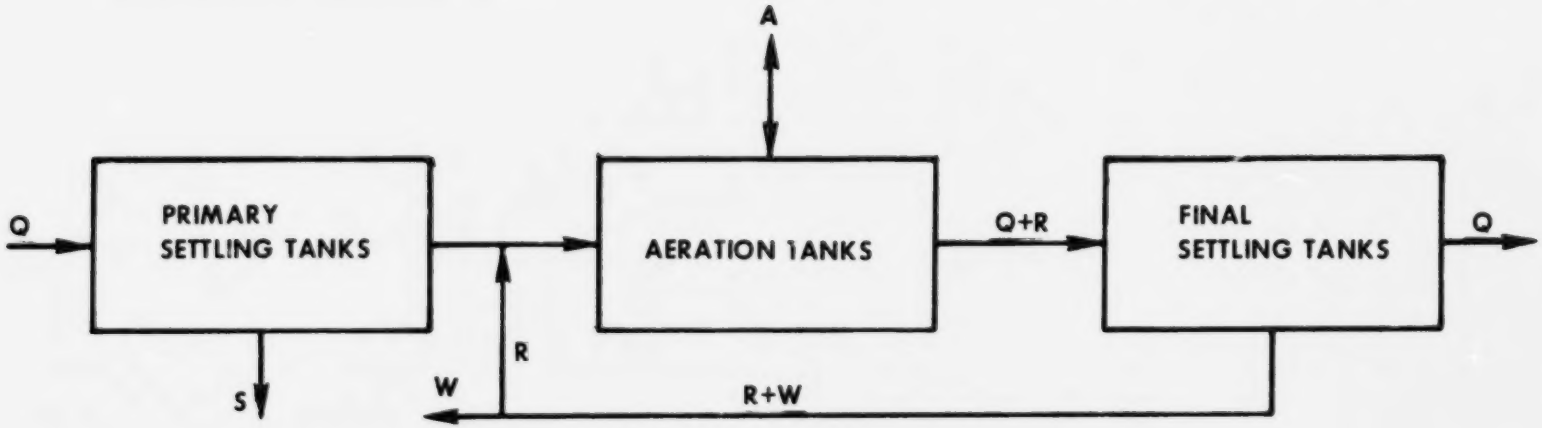
The activated sludge process has been developed to the point where many modifications of the basic process previously described exist. Some of the more important process applications and their control parameters are listed below. Flow diagrams are shown in Figure 1, 2, and 3.

1. Conventional - This is the most common form of secondary treatment found.

2. Step Aeration - This is quite similar to conventional treatment. However, the waste flow is introduced at points along the aeration tank. This results in a more uniform oxygen demand and better resistance to shock loads.

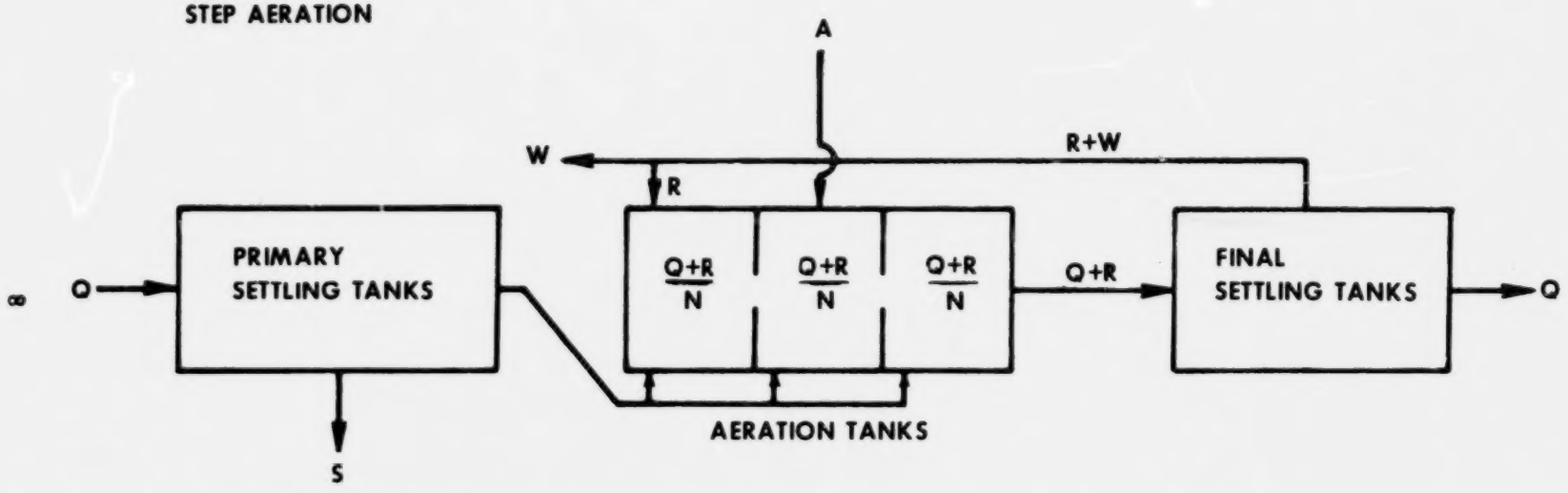
3. Contact Stabilization - This process consists of mixing a large volume of highly concentrated activated sludge with raw sewage for a very short period of time, taking advantage of the highly absorptive properties of the sludge.

FIGURE 1
CONVENTIONAL ACTIVATED SLUDGE



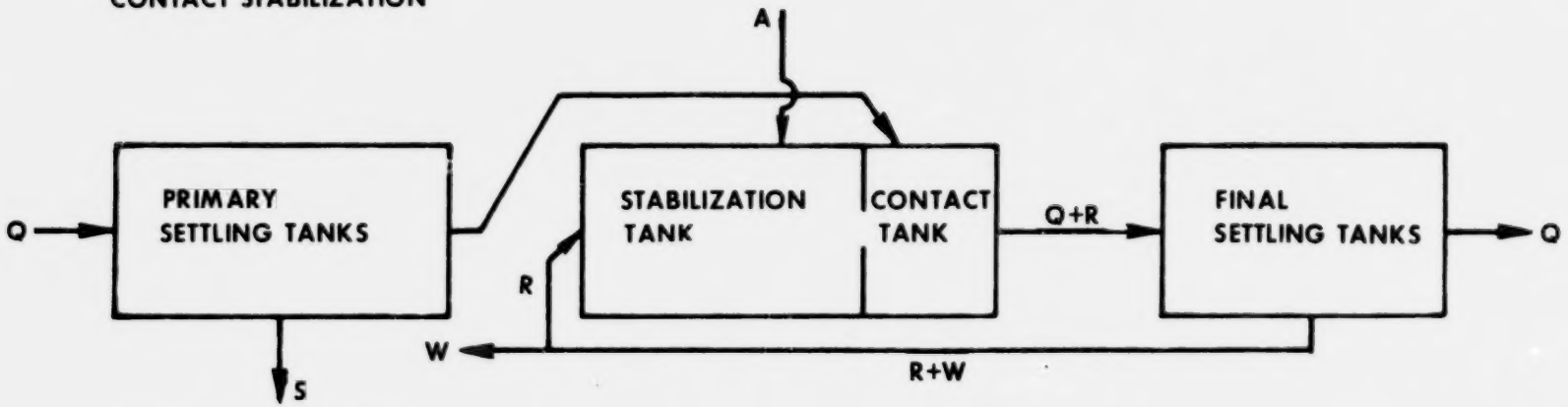
Q=RAW SEWAGE FLOW
R=RETURN SLUDGE FLOW
W=WASTE SLUDGE FLOW
S=RAW SLUDGE FLOW
A=AIR FLOW

FIGURE 2
STEP AERATION



Q=RAW SEWAGE FLOW
R=RETURN SLUDGE FLOW
W=WASTE SLUDGE FLOW
S=RAW SLUDGE FLOW
A=AIR FLOW

FIGURE 3
CONTACT STABILIZATION



Q=RAW SEWAGE FLOW
R=RETURN SLUDGE FLOW
W=WASTE SLUDGE FLOW
S= RAW SLUDGE FLOW
A=AIR FLOW

Limitations

In spite of the progress made in modifying the activated sludge process, two limitations remain. These two limitations may be classified as automation and control.

The heart of the activated sludge process lies in maintaining the proper substrate/microorganisms ratio. In activated sludge plants treating the entire sewage flow, the only means by which the substrate/microorganism ratio may be varied is by varying the microorganism concentration which is accomplished by controlling the wasting rate of waste sludge. Until recently, very little has been accomplished in applying biological kinetics in predicting quantities of excess microorganisms produced through synthesis. However, if accurate control of the activated sludge process is to be attained, it is essential that a method of control based on biological kinetics be used.

The lack of automation is another limitation on accurate control of the activated sludge process. If kinetic control is to be applied correctly, a means of making on-line measurements and corrections is essential.

It is hoped that the results of this study will show the usefulness of kinetic theory and computer control in wastewater treatment.

IV

EXPERIMENTAL PROCEDURES

Since the purpose of the contract was to gather data for cost-performance relationships, and to accurately characterize the removal relationships within the activated sludge process, a testing program was devised with the objective of supplying data which would satisfy the aforementioned goals.

For accurate characterization of the process, the testing program was divided into two phases.

Phase I consisted of sampling and the measurement of chemical and biological characteristics of the activated sludge process treating a constant flow of wastewater. A variety of substrate/microorganism ratios were studied.

Phase II consisted of sampling and the measurement of chemical and biological characteristics of the activated sludge process treating a flow of wastewater varying in a diurnal pattern. Study of one average substrate/microorganism ratio was attempted.

Plant Equipment

The secondary treatment facility at Hyperion consists of two identical batteries (labeled East and West) of aeration tanks and final settling tanks. The East battery was used for all testing and measurements. Primary effluent is fed into a distribution channel where it is mixed with return sludge, and then distributed into the aeration tanks. There are eight single-pass aeration tanks, divided into two single-pass channels, measuring 300 feet long, 15 feet deep, and 30 feet wide. The number of tanks in use may be controlled by replacement or removal of bulkheads.

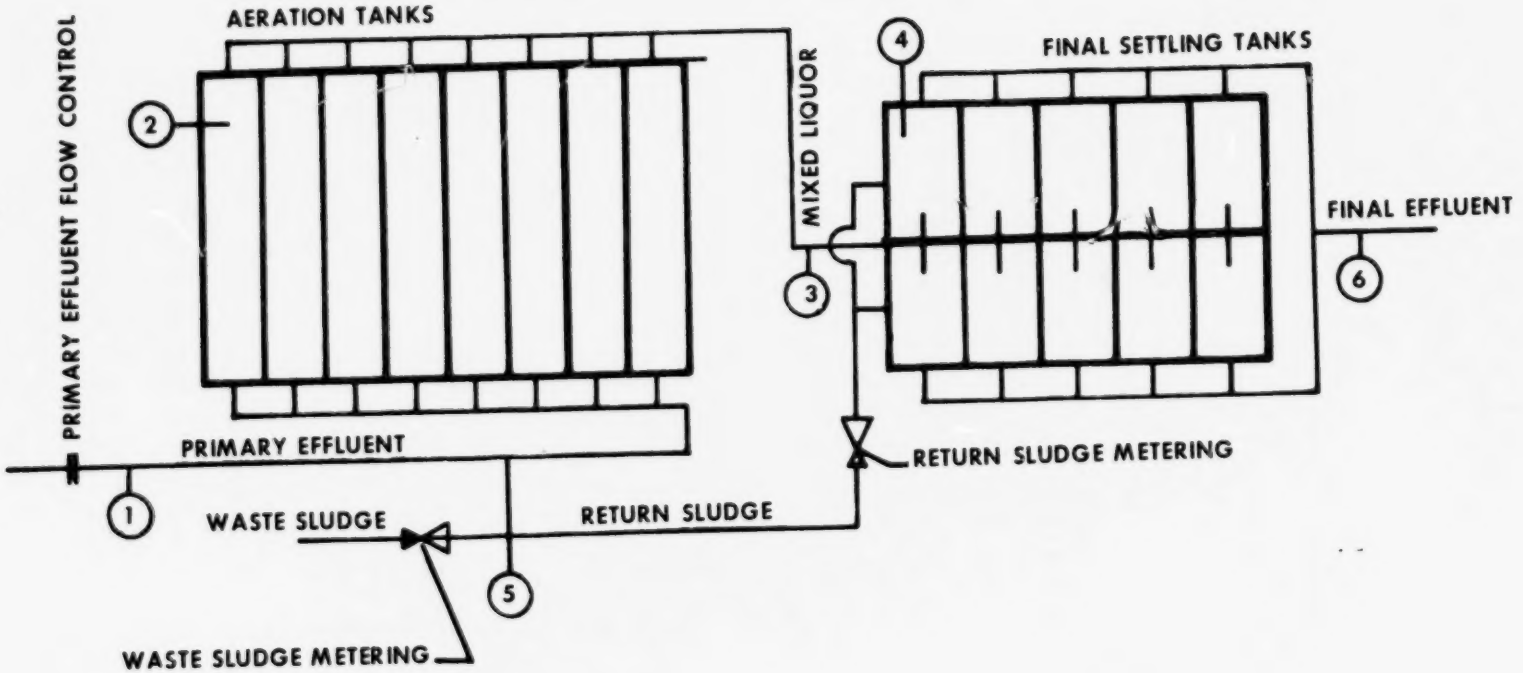
Mixed liquor is conveyed to the final settling tanks in a rectangular channel 1800 feet long. This channel leads into a distribution channel. The distribution channel feeds one set of ten final settling tanks. Each settling tank is rectangular, 125 feet long, 76 feet wide, and 15 feet deep.

The effluent from the final settling tanks is discharged over V-notch weirs into launder channels.

Equipment and operation is shown in Figure 4.

Each flow stream in the secondary treatment unit is metered and recorded. Location of the instruments is also shown in Figure 4.

FIGURE 4
SECONDARY TREATMENT UNIT
HYPERION TREATMENT PLANT



Primary effluent inflow to secondary treatment is automatically controlled by means of an orifice flow controller, motorized-gate assembly. Return activated sludge is measured through a venturi tube, recorded and controlled manually. Waste activated sludge is also metered through a venturi tube, measured and controlled manually. The air flow is metered twice. Total air flow is measured by means of an orifice plate, manometer and gauge assembly. Air flow to each tank is controlled manually, and is measured by means of an insert flow tube and a manometer.

During Phase I, only 24-hour composite samples were taken. Primary effluent was sampled at Point 1, shown in Figure 4. Aeration tank mixed liquor samples were taken at Point 3. Secondary effluent samples were taken at Point 4. Return sludge and waste sludge samples were taken at Point 5.

During Phase II, primary effluent was sampled at Point 1 with a continuous sampling device. Aeration tank mixed liquor was sampled at Points 2 and 3 with the same device. Final effluent was sampled at Point 4 with the continuous sampler. Return sludge and waste sludge were grab samples taken at Point 5.

Laboratory Techniques

In order to accurately characterize the activated sludge process, tests were made of certain key properties of the process at several key flow streams. The flow streams measured were: 1) primary effluent; 2) aerator mixed liquor; 3) return activated sludge and waste activated sludge taken from common line and 4) secondary effluent.

During Phase I, each flow stream was analyzed for the following chemical properties:

1. Chemical oxygen demand - total
2. Chemical oxygen demand - dissolved
3. Ammonia
4. Nitrite
5. Nitrate
6. Kjeldahl nitrogen - total
7. Kjeldahl nitrogen - dissolved
8. Phosphate - total
9. Phosphate - dissolved
10. Suspended solids
11. Volatile suspended solids
12. Biochemical oxygen demand - total
13. Biochemical oxygen demand - dissolved

Chemical oxygen demand, ammonia, nitrate, nitrite, Kjeldahl nitrogen, phosphate and BOD tests were performed in accordance with the procedures outlined in Standard Methods(1).

Suspended solids tests were performed, using a technique similar to that outlined in Standard Methods (1), with the exception that a Gooch crucible with glass fiber filter material was used. This method was used on primary effluent, aeration tank mixed liquor, return and waste sludges. For final effluent suspended solids, a membrane filter technique was used, in addition to the glass fiber filter technique.

The glass fiber filter technique was employed in all cases where a volatile suspended solids value was required, for the glass fiber filter mat may be incinerated without loss of weight. At low suspended solids concentrations, where greater accuracy is required, the membrane filter technique was employed. The membrane filter technique was not used with high suspended solids concentrations due to the length of filtering time.

Phosphates were analyzed by the ammonium molybdate-amino-naptho sulfonic acid method, utilizing a Technicon Auto-Analyzer readout.

The Technicon Auto-Analyzer is a grouping of individual instruments which provide a chemist a means of performing multiple analyses on a continuous basis. Samples are continuously pumped from the flow stream being tested into the instrument grouping via polyethylene tubing and peristaltic pump. The sample is then automatically treated with the proper reagents, producing a product stream of a characteristic color. The color of the product stream is then compared spectrophotometrically with the color of a standard reagent concentration. The color intensity is then equated to the concentration of the chemical compound being studied and this value is recorded in chart form.

During Phase II, the following chemical constituents were analyzed: 1) COD; 2) ammonia; 3) nitrate and 4) phosphate. Suspended solids was also measured.

COD, ammonia, nitrate, and phosphate were analyzed by auto analysis continuously during 24-hour periods. Dissolved oxygen, temperature, and pH were monitored by continuous sensing and recording devices. Suspended solids were analyzed at specific times by normal laboratory methods.

Method

The secondary treatment unit was operated in several different modes in order to provide data from a wide operational range during Phase I.

Twenty-four different loading rates were used for testing. Substrate loading was chosen as the most important variable to be studied. Substrate loading, (lbs COD/lb MLVSS) was considered the most important variable because it was the only parameter which directly related the microorganism population to wastewater strength or the amount of available food. This in turn controlled the cell growth rate.

Since the secondary treatment unit at Hyperion normally operates on a constant flow basis, the method used in varying the COD/MLVSS ratio was to vary the number of aeration tanks and the MLSS concentration therein.

Volumetric loading (lbs BOD_5/1000 ft^3 of aerator) was not chosen as a control parameter because the substrate/volume ratio is highly dependent on the strength of the primary effluent flow. The strength of the primary effluent flow at Hyperion varies little, thus the range of values for volumetric loading was limited. Also, volumetric loading only describes the substrate/volume ratio, and does not relate directly to any biological portion of the process.

Detention time in the aeration tanks was not considered an important variable in this study. The range of detention times available was from four to eight hours. It was felt that a study of varying detention time in these ranges would not stress the process enough to get extremes of testing data. If detention times were lowered below four hours, air supply and freeboard depth in hydraulic structures became limiting.

The effects of final settling detention times and surface loading rates were also studied during Phase I. These were run for each different organic loading. Table 1 shows the test schedule.

Table 2 shows the average values of pertinent control parameters for each test in Phase I.

In a steady-state process, such as that used during testing in Phase I, the process loading is easily controlled. However, a number of ways of expressing process loading exist. The most conventional is lbs BOD_5/lb MLSS. As stated previously, this is an indirect relation of the quantity of biodegradable substrate to the mass of bacteria present. It is difficult to use this as an operational control because of the five-day lag involved in BOD_5 tests. A more adaptable control term is the COD/MLVSS ratio. The COD test can be completed in four hours, giving a quick indication of substrate concentration. Admittedly,

TABLE 1

TESTING SCHEDULE - PHASE I

TEST NUMBER	SUBSTRATE LOADING LBS COD/LB MLVSS	SECONDARY SETTLING SURFACE LOADING RATE gpm/ft^2	TEST DURATION
1	0.84	520	9-10-68 to 9-25-68
2	0.90	870	9-26-68 to 9-27-68
3	0.60	520	9-28-68 to 10-13-68
4	0.53	870	10-14-68 to 10-15-68
5	0.64	520	10-16-68 to 10-31-68
6	0.69	870	11-1-68 to 11-3-68
7	0.90	520	11-4-68 to 11-18-68
8	1.02	870	11-19-68 to 11-20-68
9	1.29	520	11-21-68 to 12-5-68
10	1.25	870	12-6-68 to 12-8-68
11	1.59	520	12-9-68 to 12-26-68
12	1.13	870	12-27-68 to 12-29-68
13	2.39	520	12-30-68 to 1-13-69
14	2.13	870	1-14-69 to 1-15-69
15	1.45	520	1-16-69 to 1-30-69
16	2.08	870	1-31-69 to 2-3-69
17	2.72	520	2-4-69 to 2-17-69
18	3.69	870	2-18-69 to 2-19-69
19	2.61	521	2-20-69 to 3-6-69
20	2.13	870	3-7-69 to 3-9-69
21	2.25	520	3-10-69 to 3-24-69
22	2.39	870	3-25-69 to 3-26-69
23	1.11	520	3-27-69 to 4-13-69
24	0.97	870	4-14-69 to 4-15-69

RESULTS OF MEASUREMENT PROGRAM - PHASE I

TABLE 2

TEST NUMBER	FLOW MGD	LBS COD / LBS MLVSS	MLSS mg/l	AERATION TIME HOURS	AIR SUPPLY FT^3/GAL	AERATION TANK pH	AERATION TANK TEMP °F	AERATION TANKS IN SERVICE	WASTE SLUDGE MGD	WASTE SLUDGE CONC. mg/l	RETURN SLUDGE MGD	RETURN SLUDGE CONC. mg/l	FINAL SETTLING TIME HRS.	FINAL SETTLING SURFACE LOADING RATE GMP/FT^2
1	49.5	0.84	1996	6.5	1.40	7.5	80	6	0.94	5720	25.5	5720	5.1	520
2	49.4	0.90	2000	6.5	1.40	7.6	80	6	0.58	6070	20.7	6070	3.1	870
3	49.6	0.60	2983	6.5	1.40	7.3	80	6	0.67	7472	29.8	7472	5.1	520
4	49.3	0.53	3120	6.5	1.40	7.5	79	6	0	7100	28.1	7100	3.1	870
5	49.9	0.64	3436	5.5	1.40	7.4	76	5	0.52	7866	34.5	7866	5.1	520
6	49.9	0.69	2850	5.5	1.82	7.4	75	5	0.21	6926	32.0	6926	3.0	870
7	50.0	0.90	2917	4.5	1.56	7.5	78	4	0.88	7310	31.7	7310	5.1	520
8	49.3	1.02	2810	4.5	1.56	7.4	-	4	0.90	7180	26.8	7180	3.1	870
9	49.7	1.29	1866	4.5	1.56	7.5	-	4	1.16	5758	21.3	5758	5.1	520
10	49.2	1.25	1890	4.5	1.56	7.5	72	4	1.00	3400	15.5	3400	3.1	870
11	49.1	1.59	1613	4.5	1.52	7.1	70	4	1.10	5482	18.2	5482	5.2	520
12	49.2	1.13	1660	4.5	1.52	7.3	-	4	1.12	5380	18.7	5380	3.1	870

RESULTS OF MEASUREMENT PROGRAM - PHASE I

TABLE 2

TEST NUMBER	FLOW MGD	LBS COD / LBS MLVSS	MLSS mg/l	AERATION TIME HOURS	AIR SUPPLY FT³/GAL	AERATION TANK pH	AERATION TANK TEMP °F	AERATION TANKS IN SERVICE	WASTE SLUDGE MGD	WASTE SLUDGE CONC. mg/l	RETURN SLUDGE MGD	RETURN SLUDGE CONC. mg/l	FINAL SETTLING TIME HRS.	FINAL SETTLING SURFACE LOADING RATE GMP/FT²
1	49.5	0.84	1996	6.5	1.40	7.5	80	6	0.94	5720	25.5	5720	5.1	520
2	49.4	0.90	2000	6.5	1.40	7.6	80	6	0.58	6070	20.7	6070	3.1	870
3	49.6	0.60	2983	6.5	1.40	7.3	80	6	0.67	7472	29.8	7472	5.1	520
4	49.3	0.53	3120	6.5	1.40	7.5	79	6	0	7100	28.1	7100	3.1	870
5	49.9	0.64	3436	5.5	1.40	7.4	76	5	0.52	7866	34.5	7866	5.1	520
6	49.9	0.69	2850	5.5	1.82	7.4	75	5	0.21	6926	32.0	6926	3.0	870
7	50.0	0.90	2917	4.5	1.56	7.5	78	4	0.88	7310	31.7	7310	5.1	520
8	49.3	1.02	2810	4.5	1.56	7.4	-	4	0.90	7180	26.8	7180	3.1	870
9	49.7	1.29	1866	4.5	1.56	7.5	-	4	1.16	5758	21.3	5758	5.1	520
10	49.2	1.25	1890	4.5	1.56	7.5	72	4	1.00	3400	15.5	3400	3.1	870
11	49.1	1.59	1613	4.5	1.52	7.1	70	4	1.10	5482	18.2	5482	5.2	520
12	49.2	1.13	1660	4.5	1.52	7.3	-	4	1.12	5380	18.7	5380	3.1	870

TABLE 2 (Cont'd.)

RESULTS OF MEASUREMENT PROGRAM - PHASE I

TEST NUMBER	FLOW MGD	LBS COD / LBS MLVSS	MLSS mg/l	AERATION TIME HOURS	AIR SUPPLY FT³/GAL	AERATION TANK pH	AERATION TANK TEMP °F	AERATION TANKS IN SERVICE	WASTE SLUDGE MGD	WASTE SLUDGE CONC. mg/l	RETURN SLUDGE MGD	RETURN SLUDGE CONC. mg/l	FINAL SETTLING TIME HRS.	FINAL SETTLING SURFACE LOADING RATE GMP/FT²
13	49.1	2.39	1050	4.5	1.52	-	67	4	1.40	3770	19.0	3770	5.2	520
14	49.7	2.13	1053	4.5	1.52	7.3	66	4	1.26	3640	18.2	3640	3.0	870
15	49.2	1.45	999	6.5	1.60	7.6	64	6	1.26	3546	20.8	3546	5.2	520
16	49.2	2.08	790	6.5	1.60	7.8	-	6	1.23	3330	14.2	3330	3.1	870
17	49.3	2.72	628	6.5	1.60	7.7	67	6	1.85	2642	13.2	2642	5.1	520
18	49.3	3.96	603	6.5	1.60	7.5	71	6	1.91	3506	10.3	3506	3.1	870
19	49.3	2.61	570	6.5	1.60	7.7	64	6	1.44	2900	10.7	2900	5.1	520
20	49.4	2.13	610	6.5	1.60	-	64	6	1.25	2960	12.8	2960	3.1	870
21	49.2	2.25	706	6.5	1.60	7.7	67	6	1.39	3309	14.8	3309	5.2	520
22	49.3	2.39	656	6.5	1.60	7.5	71	6	0.53	4409	10.5	4409	3.1	870
23	50.2	1.11	1485	6.5	1.60	7.5	71	6	0.77	5010	19.0	5010	5.0	520
24	49.4	0.97	1470	6.5	1.60	7.5	72	6	0.81	6270	20.0	6270	3.1	870

the COD does not directly measure the quantity of organic material available for biological synthesis, but neither does BOD_5. Both terms are only measurements for synthesis of the substrate.

Total organic carbon has been suggested as a more direct indicator of biodegradable substrate. However, TOC measures not only the biodegradable carbon, but any other carbonaceous material which is not readily degradable in a biological treatment system.

The COD/MLVSS is a good loading parameter for an activated sludge system. The COD test is quick and can be related to the BOD_5 test. During the contract testing period, the average COD of the primary effluent was 2.06 times the average BOD_5. The COD to BOD_5 ratio had a maximum value of 2.20 and a minimum value of 1.90. MLVSS is possibly a better indicator of the biological population than MLSS. As shown in Figure 5, the percent volatiles of MLSS varies with the concentration of MLSS. By using MLVSS, a more accurate indication of biological activity might be attained, as the active organisms are probably some portion of the total percent volatiles.

During Phase II, the secondary treatment facility treated a waste flow varying in quantity and concentration in order to study any transient changes in activated sludge characteristics.

Daily step flow changes were made according to the following schedule:

TABLE 3

TIME	FLOW
9:00 AM	50 MGD
11:00 AM	75 MGD
1:00 PM	100 MGD
3:30 PM	87.5 MGD
6:30 PM	75 MGD
9:30 PM	62.5 MGD
12:30 AM	50 MGD
3:30 AM	37.5 MGD
6:30 AM	25 MGD

Sampling was done one-half hour before each flow change.

An attempt was made to maintain a constant MLSS concentration in the aeration tanks, and a constant sludge blanket depth in the secondary clarifiers. Air was supplied to the aeration tanks at a varying rate. An attempt was made to keep the air/sewage ratio constant, but was hindered by the inability of the compressors to deliver enough air at peak flow. The rate of air supplied varied according to the following schedule:

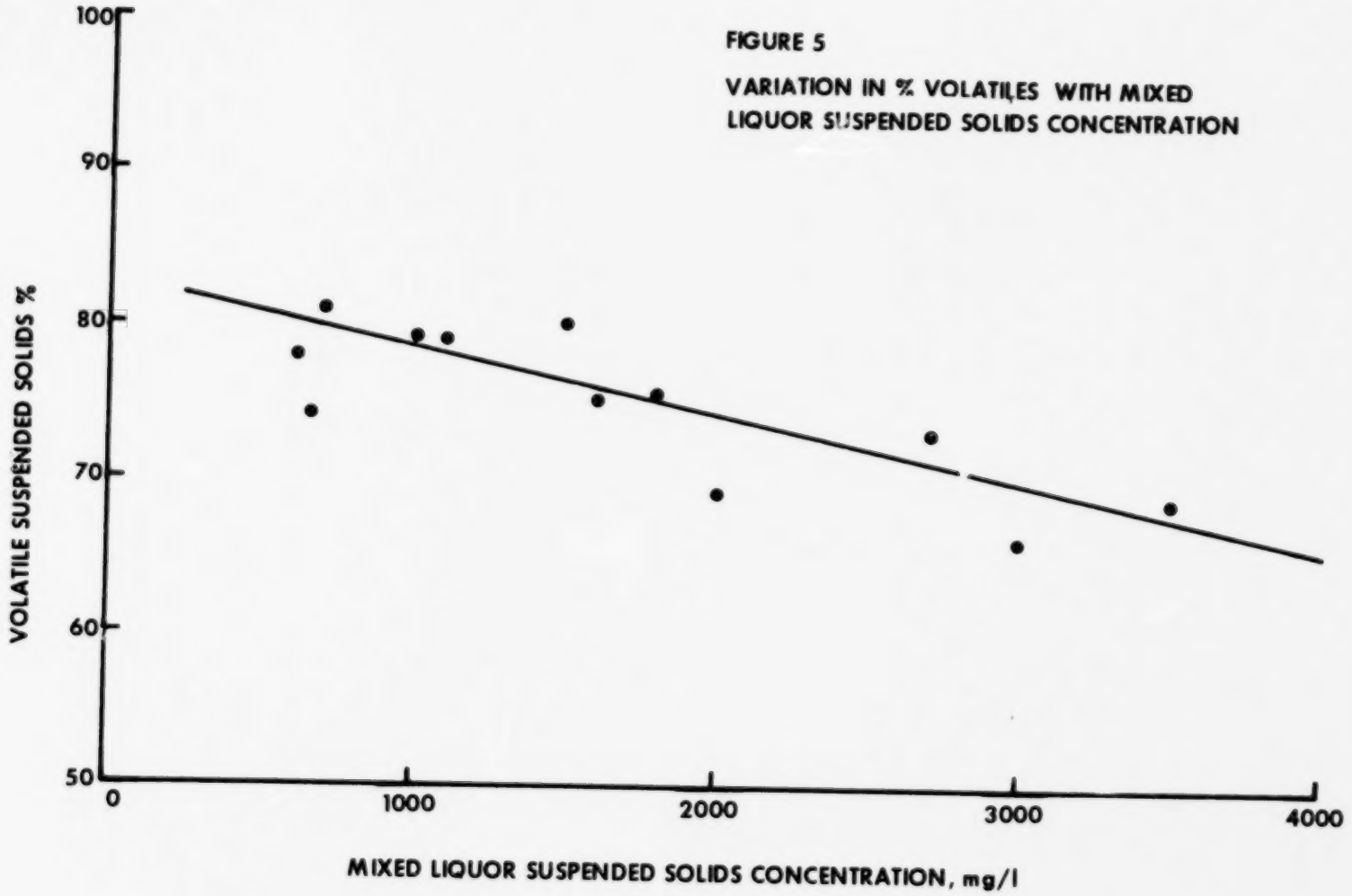


FIGURE 5

VARIATION IN % VOLATILES WITH MIXED LIQUOR SUSPENDED SOLIDS CONCENTRATION

TABLE 4

TIME	AIR/SEWAGE (FT^3/GAL)
9:00 AM	1.50
11:00 AM	1.10
1:00 PM	0.82
3:30 PM	0.87
6:30 PM	1.15
9:30 PM	1.35
12:30 AM	1.50
3:30 AM	1.50
6:30 AM	1.50

During this phase, the secondary treatment unit was first operated in a steady-state mode in order to get background data for the rapid sampling instrument which was to be used for analysis of all characteristics but suspended solids and BOD_5. The steady-state operation lasted from June 30, 1969, to July 4, 1969. The actual on-line testing for transient effects began July 7, 1969, and lasted until July 11, 1969.

Continuously recording instruments used during Phase II were air flow, pH, temperature and dissolved oxygen recorders. Temperature, pH, and dissolved oxygen were recorded at the inlet and outlet of the aeration system. The dissolved oxygen instrument did not prove reliable measuring dissolved oxygen in the aeration tanks. It was found that the electrode was being fouled by hydrogen sulfide from the aeration process air. At Hyperion, aeration air is drawn from the interior of covered primary settling tanks. The air under the tank covers has a high percentage of hydrogen sulfide.

V

THEORETICAL CONSIDERATIONS

Many parameters have been used in the past to characterize activated sludge process operations. These parameters, such as organic loading, sludge age, and substrate to volume ratio have been used with varying success in the past. Part of the contract study was evaluation of characterization parameters based on the synthesis of carbon, nitrogen, and phosphorus into new cellular material.

Two methods of characterization were investigated. One method is based on the Monod equation for enzyme catalyzed reactions(2), the other is based on the theory that a varying mass of new cells are synthesized for every mass of substrate uptake.

A more common term for the first method mentioned is "Mean Cell Residence Time," proposed originally by Pearson(3). The second method is that theorized by Robert Smith of the Cincinnati Water Research Laboratory.

The "Mean Cell Residence Time" theory is based on the Monod equation. The Monod equation states that the cellular growth rate is proportional to the substrate concentration according to the following equation.

$$u = \frac{\hat{u}\, S}{K_s + S}$$

where:

u = specific cell growth rate

S = substrate concentration

$\hat{u}$ = maximum growth rate at infinite substrate concentration

K_s = constant

In the region of substrate concentrations encountered in activated sludge treatment, the Monod equation can be approximated by a first order reaction. That is the specific growth rate is directly proportional to the substrate concentration. For steady-state conditions, the above relationship has been written as:

$$1/\theta_c = Y(q) - K_d$$

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where:

$1/\theta_c$ = net growth rate, $days^{-1}$

Y = yield coefficient, $\frac{(\text{lbs cells prod})}{(\text{lbs subst. rem.})}$

q = substrate removal rate, $\frac{(\text{lbs subst. rem.})}{(\text{lbs cells-day})}$

K_d = endogenous respiration constant

Figure 6 shows the equation plotted with data obtained during testing. It is seen that the yield coefficient and endogenous respiration are constants, and that net growth rate is directly proportional to the substrate removal rate. Net growth rate is also directly proportional to the substrate loading rate. See Figure 7.

Robert Smith proposes that the maximum rate constant (K_s) used in the Monod equation for microorganic growth is not a constant, but varies with something like loading. This is based on studies by Stack[4], who has related the variation in the rate constant (K_s) to detention time in bench scale experiments. This variation in the rate constant with loading can be seen using a simplified model. By writing COD mass balances, the following equation can be derived:

$$\frac{\text{Total COD}_{in} - \text{Soluble COD}_{out}}{\text{det time x soluble COD}_{out}} = k \times \text{MLVSS}$$

The values for "k" vary as shown in Figure 8.

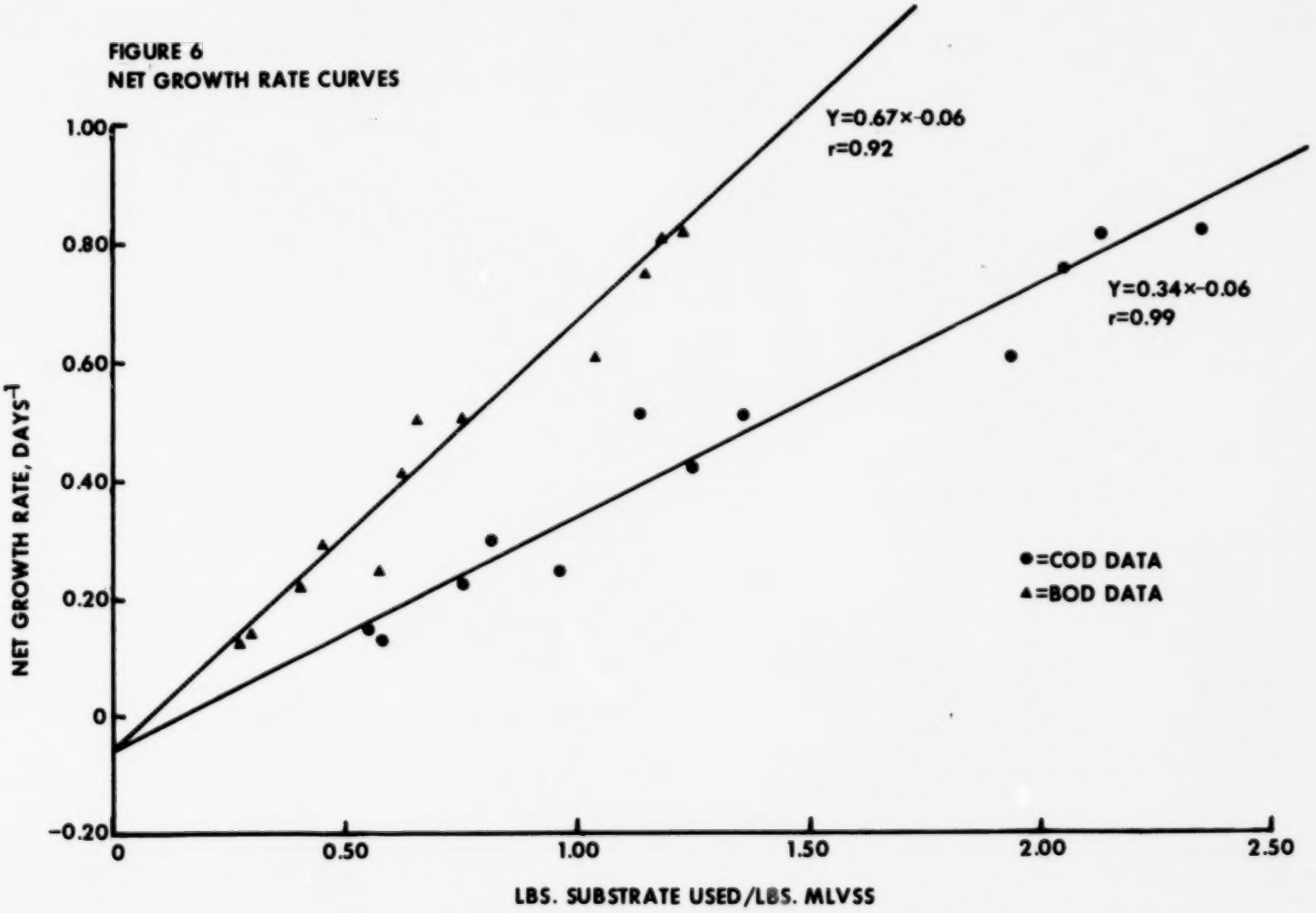
The relationship between maximum rate constant and inverse loading used by Robert Smith[5] in computer analysis of testing data is given by the following equation:

Maximum rate constant, $days^{-1}$ = 5.341 - 2.540 ln (inverse loading)

This is derived from the relationship shown in Figure 9.

Some diversity of opinion exists as to which parameter is more accurate. It is claimed by Cincinnati Water Research Laboratory personnel that the activated sludge process is apparently more effective in smoothing out variations in performance caused by time varying loads than would have been predicted on the basis of the Monod equation alone. It must also be pointed out that the net growth rate does vary with loading much in the same manner as does maximum rate constant with inverse loading. It is hoped that the differences between the two theories may be resolved in a future study.

FIGURE 6
NET GROWTH RATE CURVES



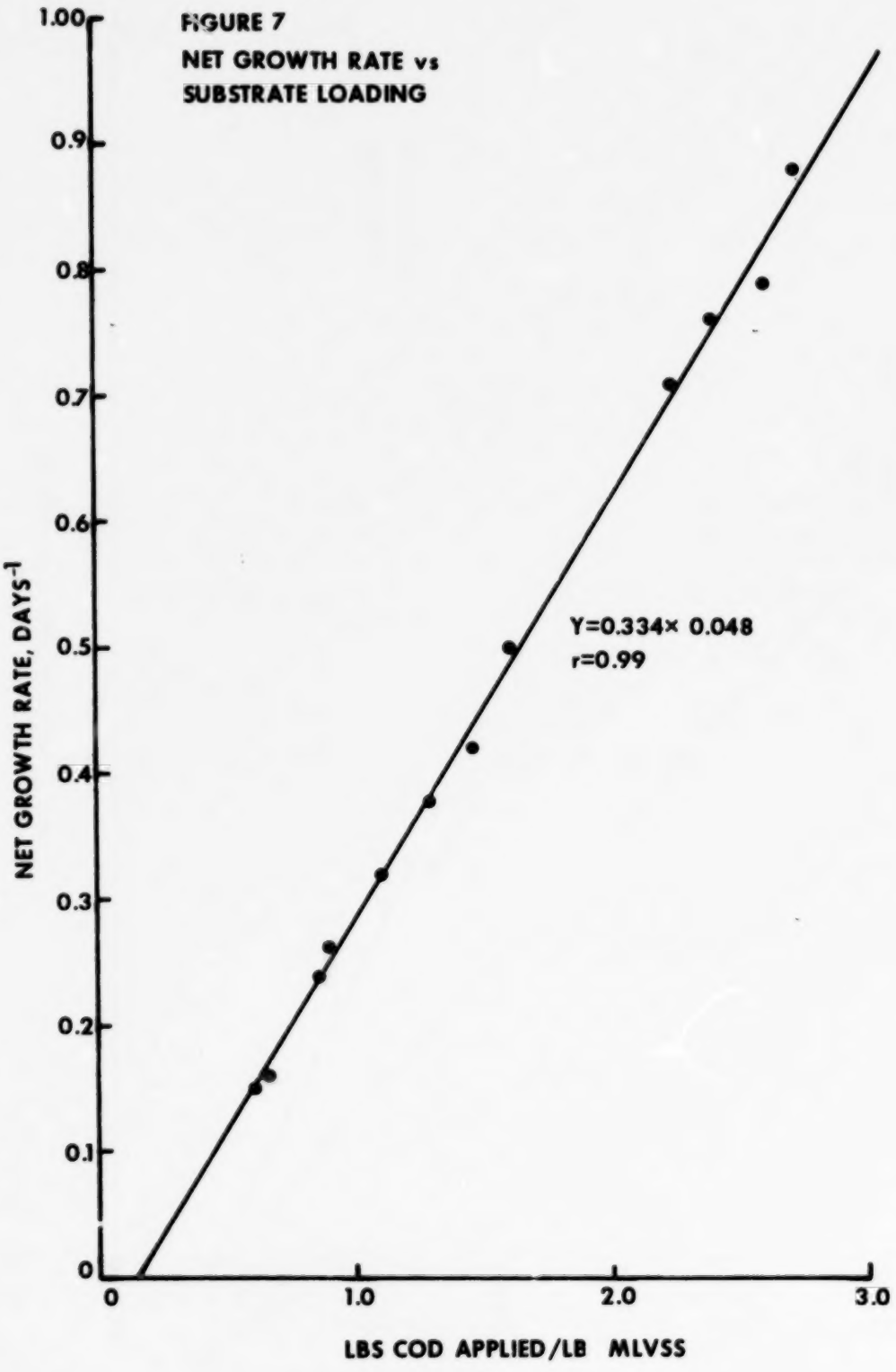


FIGURE 7
NET GROWTH RATE vs
SUBSTRATE LOADING
1.00
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
NET GROWTH RATE, DAYS⁻¹
Y=0.334× 0.048
r=0.99
0
1.0
2.0
3.0
LBS COD APPLIED/LB MLVSS

FIGURE 8

VARIATION IN RATE CONSTANT WITH LOADING IN SIMPLE MODEL

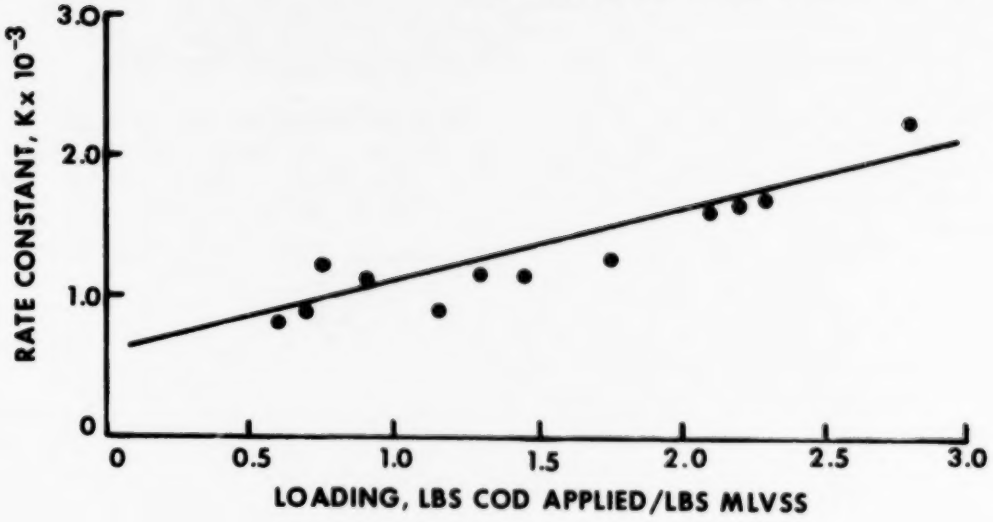
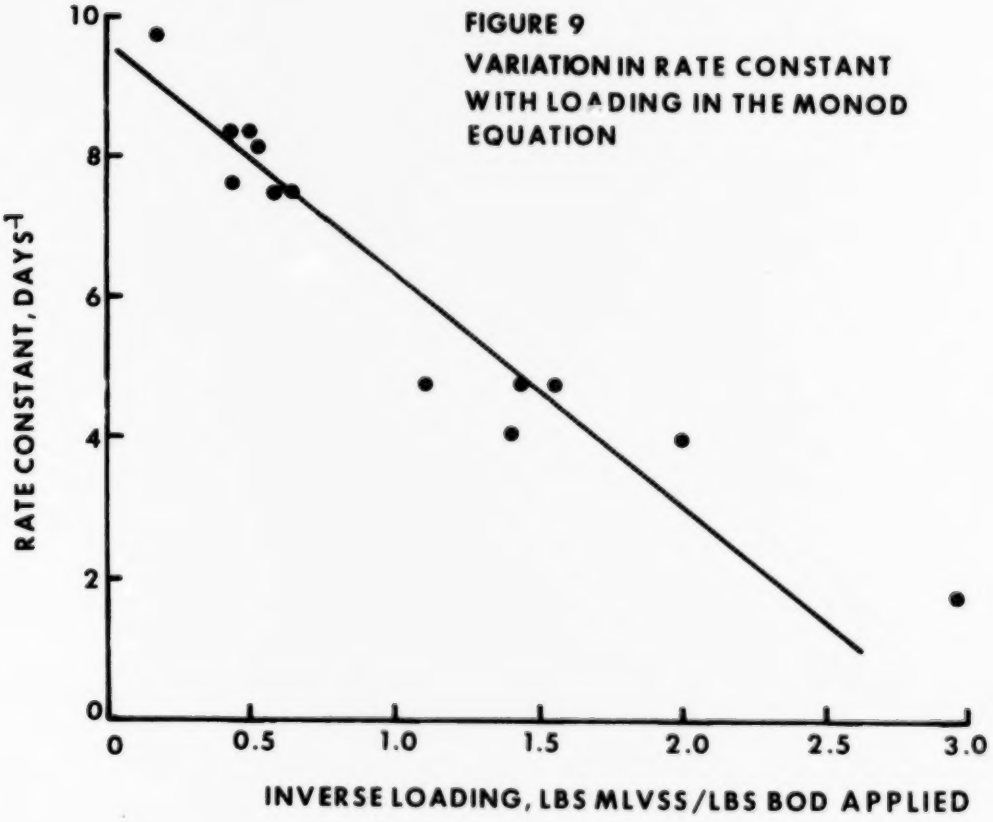


FIGURE 9

VARIATION IN RATE CONSTANT WITH LOADING IN THE MONOD EQUATION



Two different, but not opposing, theories of the biological kinetics involved in synthesis and growth in the activated sludge process exist. They are: the "Mean Cell Residence Time" as proposed by Pearson, and that proposed by Robert Smith of the Cincinnati Water Research Laboratory. Both state the biological synthesis and growth vary with process loading, but differ in regards to the constants and magnitudes involved.

Both parameters may be used for characterizing the activated sludge process, but more data and research is needed to validate each theory. Because the "Mean Cell Residence Time" give better correlation with test data, it was used in data analysis for this report.

VI

EXPERIMENTAL RESULTS - PHASE I

COD and BOD_5 REMOVAL

The measure of removal of organic matter from wastewater is generally accomplished by expressing removal in terms of COD and BOD_5. It has generally been accepted fact among researchers and engineers that COD or BOD_5 removal is accomplished through biological utilization of the substrate for cell synthesis. In the contract study, COD and BOD_5 removals were studied in order to find a correlation between COD or BOD_5 removal and operational parameters. Once such a correlation is established, operational control through the use of on-line instrumentation and computer control may be feasible. In addition, optimization of plant design to meet removal criteria would be enhanced.

One major disadvantage of using COD or BOD_5 as a measure of substrate is that neither is a direct measurement of the substrate actually utilized. An example of a step in the right direction is the use of total organic carbon in wastewater analyses. Work has been done with total organic carbon at Hyperion. Using an experimental instrument, values of total organic carbon were determined and compared with BOD_5 values. BOD_5 for final effluent averaged 32 mg/l while TOC values for final effluent averaged 4 mg/l. The TOC values are greater because the test measures organic carbon not measureable in the BOD_5 analysis.

For this study, the only available means of indicating substrate concentrations was with BOD_5 and COD. As a means of quick operational control, BOD_5 loadings have little use. However, they can be used for comparison of past operations, and for design purposes.

In Figures 10 and 11, COD and BOD_5 loadings are shown correlated to respective percentage removals. The COD curves show a semi-log correlation. The mathematical expression for COD removal is:

$$Y = 1173e^{-0.835X}$$

The data correlation is good, with a correlation coefficient of 0.91.

The mathematical expression for BOD_5 removal is:

$$Y = 81310e^{-0.1294X}$$

The data correlation is excellent, with a correlation coefficient of 0.95.

In Figure 10 and 11, the effect of detention time in the aeration tank is also shown. Removal data from the 4.5-hour aeration times plots well with the removal data from the 6.5-hour detention times. It seems that little benefit is gained from the use of longer detention times unless some added effect such as nitrification is desired.

Figure 12 shows net growth rate correlated with soluble COD in the secondary effluent.

The mathematical expression is:

$$Y = 0.22X-0.41$$

The data has good correlation, as the correlation coefficient is 0.84. It should be noted that at zero growth rate, or limited feeding, a minimum COD results. Thus, 100% removal of COD cannot be obtained in the activated sludge process treating domestic sewage.

Figures 13 and 14 show the relation between net growth rate and substrate removal. The relation between net growth rate and COD removal is:

$$Y = 810e^{-0.0941X}$$

with a correlation coefficient of 0.89.

The mathematical relation between net growth rate and BOD_5 removed is:

$$Y = 156115e^{-0.140X}$$

with a correlation coefficient of 0.86.

Both net growth rate and organic loading have shown good removal correlation with COD and BOD_5. The relation shown between organic loading and net growth rates in Figure 7 indicates that net growth rate and organic loading could be used interchangeably as an operational parameter.

Good correlation between organic loading and COD and BOD_5 removals has been found. Good correlation between net growth rate and COD and BOD_5 removals was also found.

FIGURE 10
COD REMOVAL vs SUBSTRATE LOADINGS

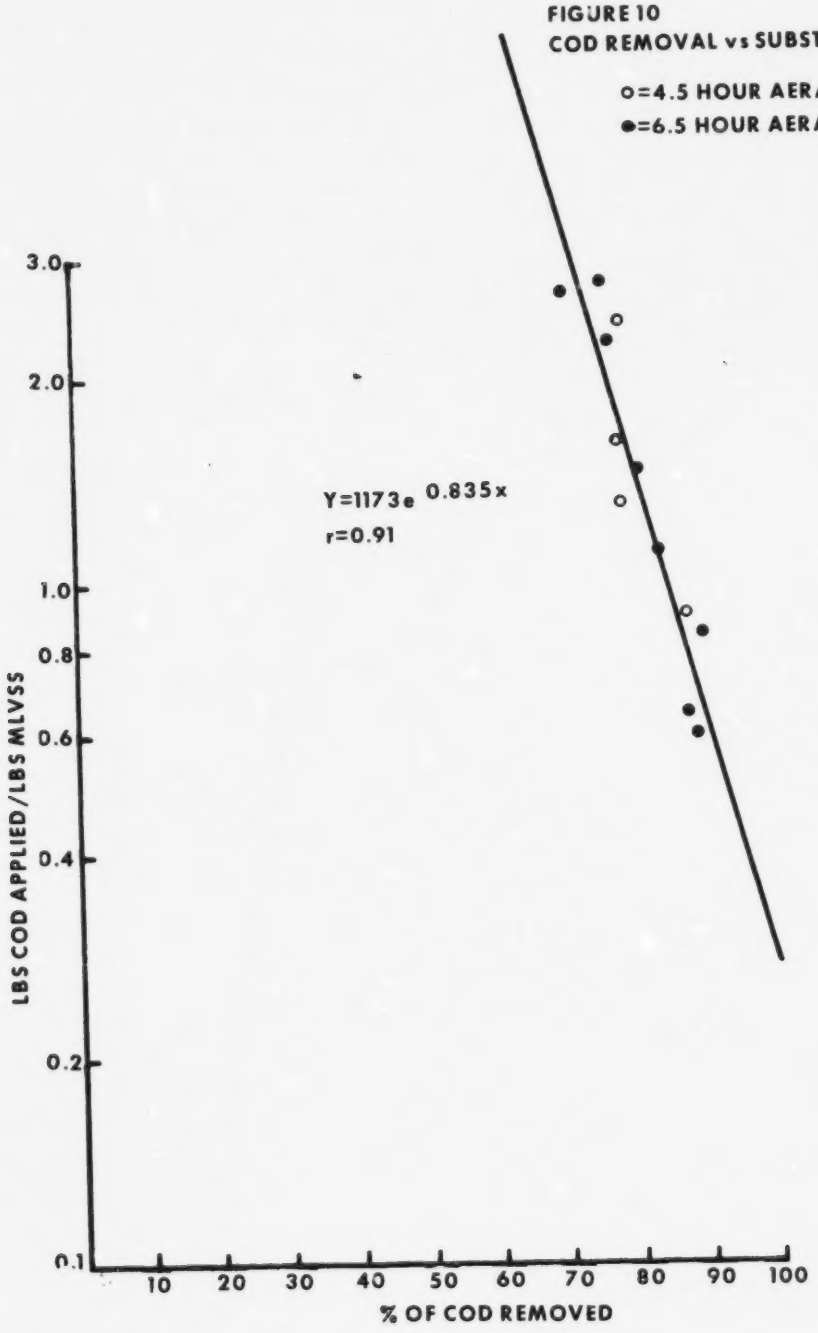


FIGURE 11
BOD REMOVAL vs PROCESS LOADING

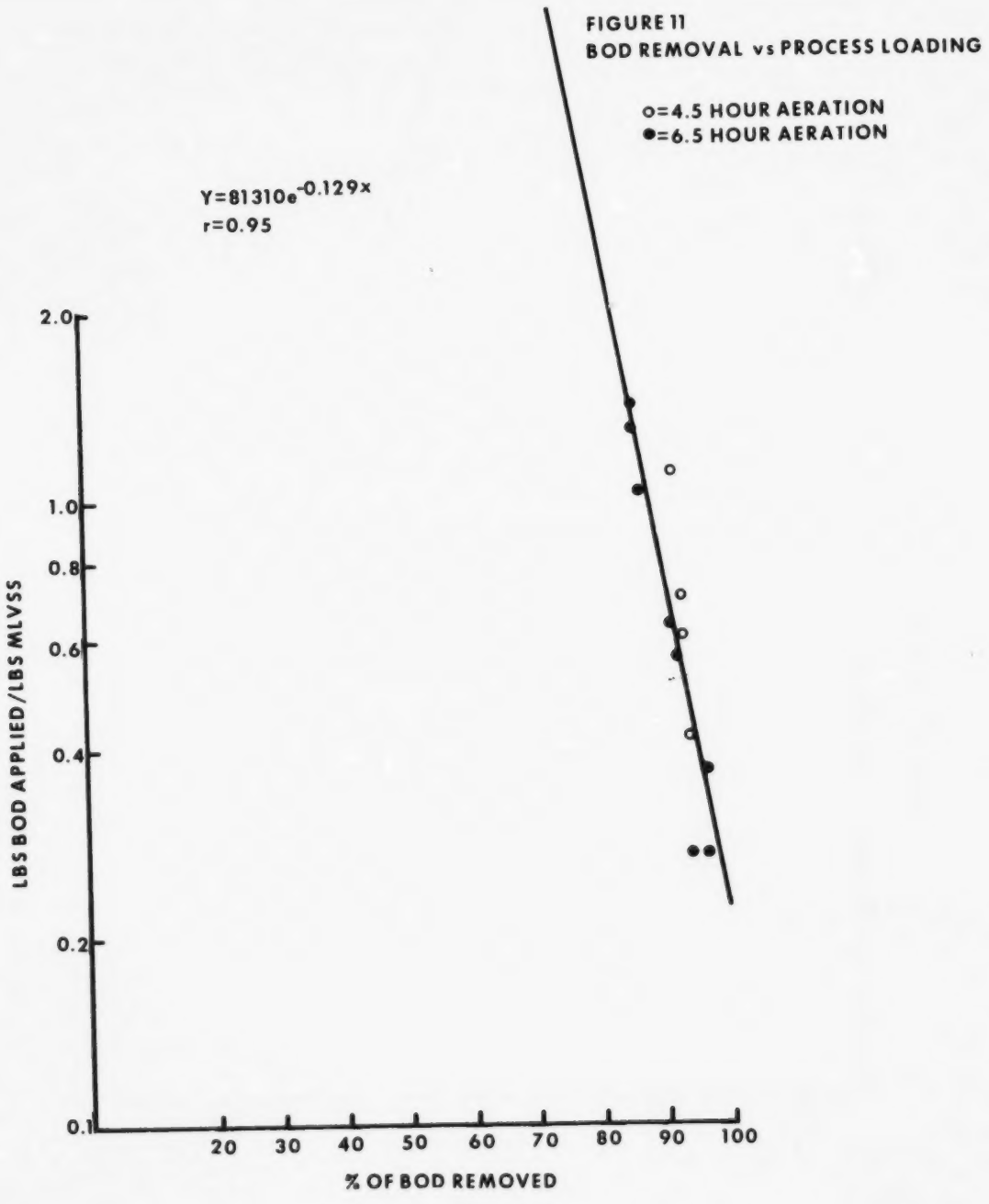


FIGURE 12
MINIMUM COD OBTAINABLE IN SECONDARY EFFLUENT WITH ACTIVATED SLUDGE

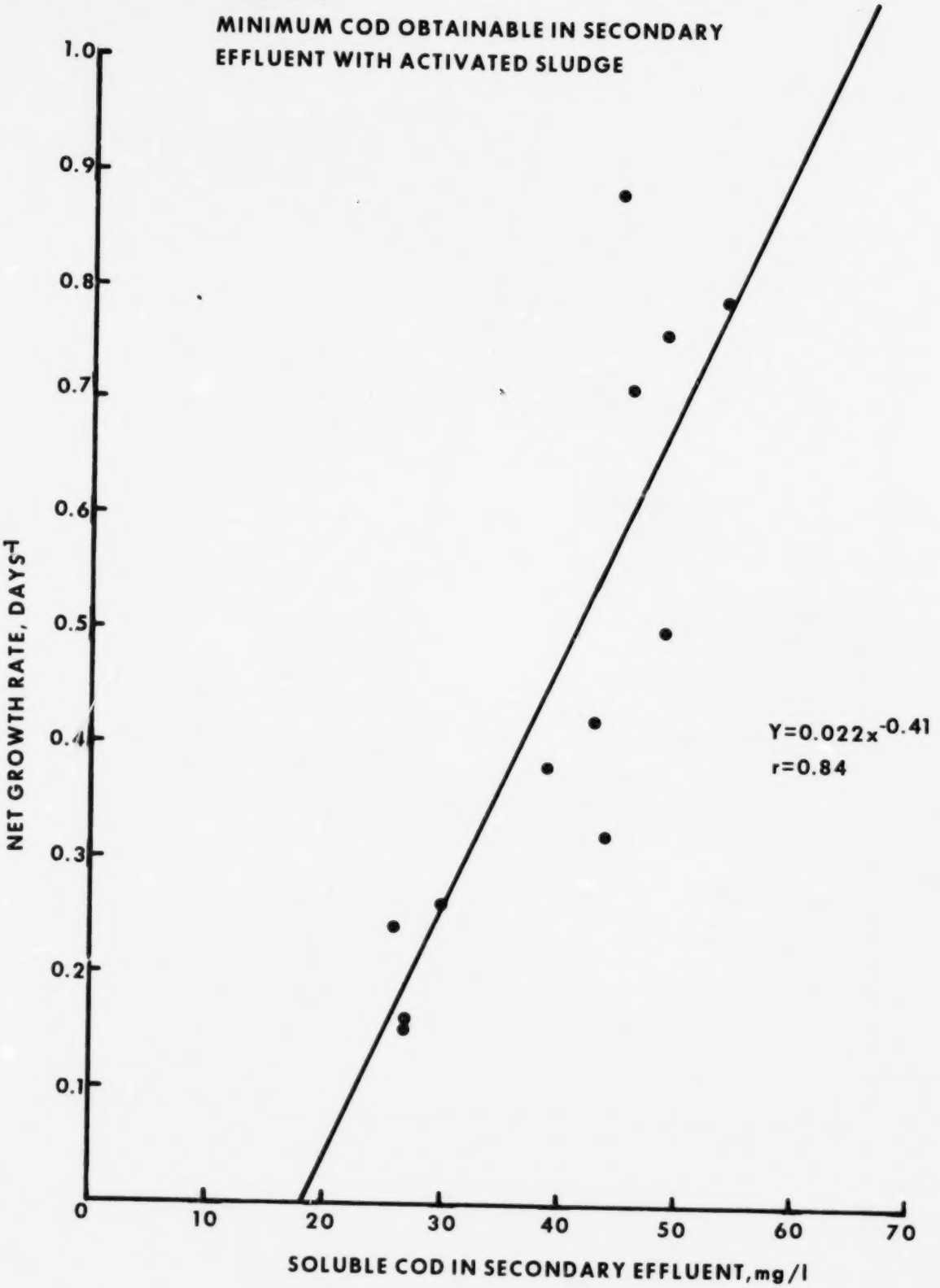
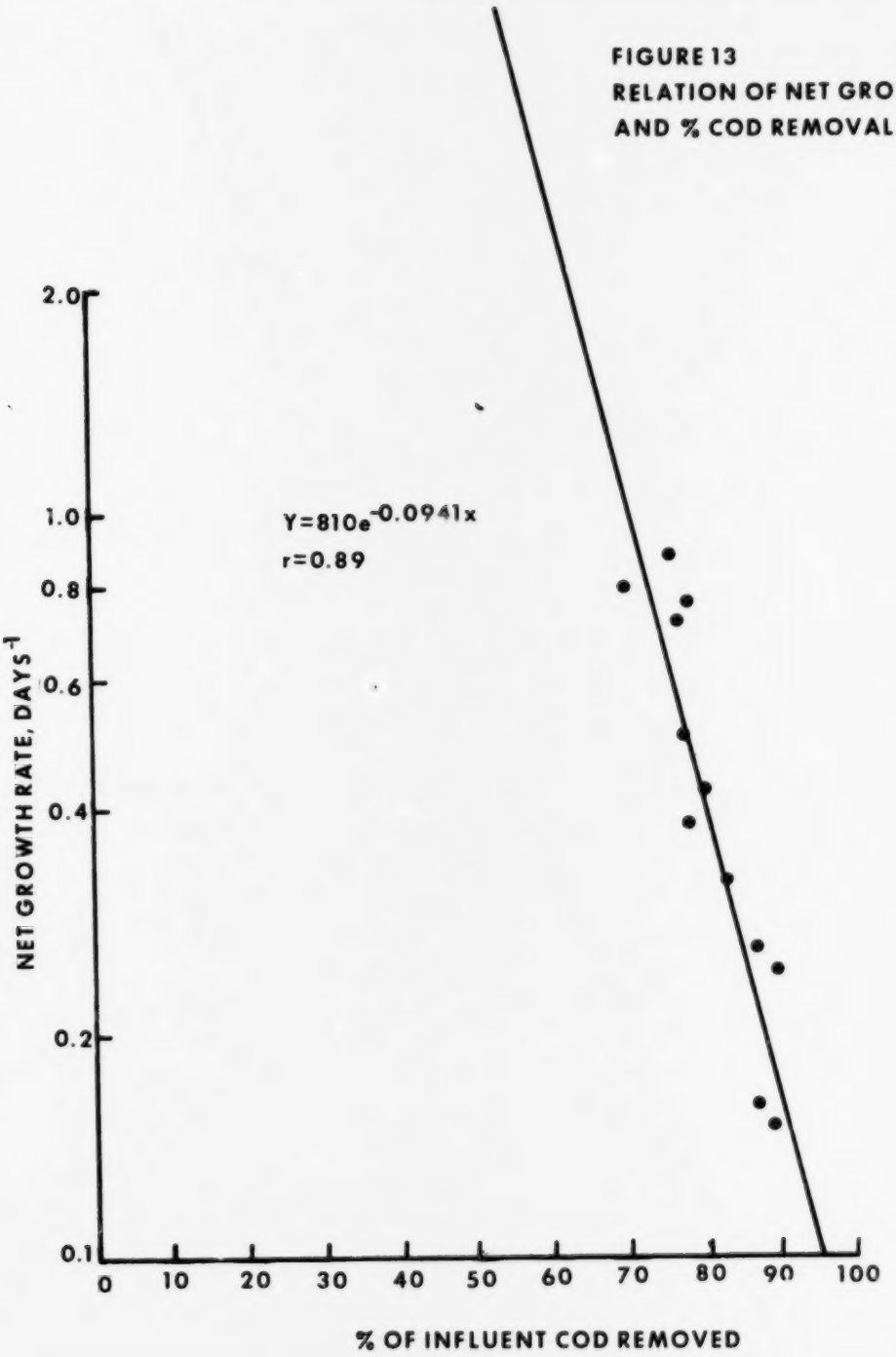


FIGURE 13
RELATION OF NET GROWTH RATE
AND % COD REMOVAL



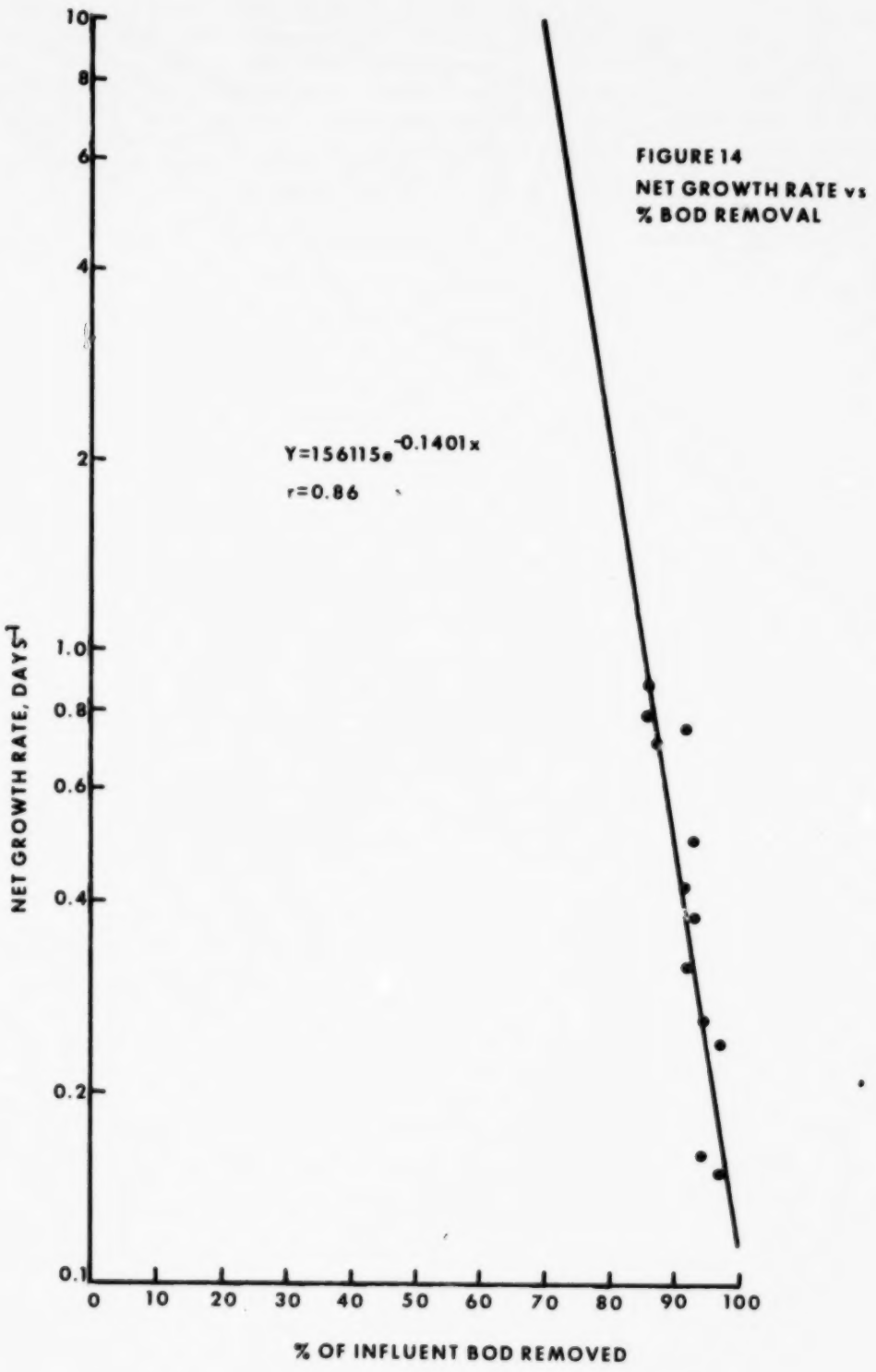


FIGURE 14
NET GROWTH RATE vs
% BOD REMOVAL

In characterizing the activated sludge process for carbon removal, it was decided to rate removal effectiveness with the amount of carbon entering the process. Due to difficulties involved in analyzing sewage streams for pure carbon, indicators of the amount of carbon available for biological use were studied with removal effectiveness. The results (Figures 11, 12, 13 and 14) show that the activated sludge process can be characterized with regards to carbon removal with a high degree of predictability.

VII

SUSPENDED SOLIDS REMOVAL

Suspended solids removal in the activated sludge process is dependent on two factors; namely, the biological activity or net growth rate of the process, and the efficiency of the final settler. As mentioned before, two different final settling rates were used for each change in net growth rate.

Figures 15 and 16 show suspended solids removal plotted against growth rate for each settling rate. Figure 15 is mathematically expressed as:

$$Y = 0.026X + 2.67$$

with a correlation coefficient of 0.84

$$Y = 0.018X + 1.87$$

with a correlation coefficient of 0.84

McKinney[7] has shown that the settleability or flocculability of the activated sludge floc is dependent on the growth rate of the process. If the system is operated at a high growth rate, the relative energy level is sufficiently high to keep all the microorganisms completely dispersed. At lower growth rates, the energy of the system is lower, and cells lack energy to overcome the forces of attraction once they have collided, thereby promoting floc formation.

The slopes of the curves in Figures 15 and 16 show the tendency of increasing suspended solids in the effluent with increasing net growth rate or substrate loading. Visual observations during testing showed that as net growth rate increased, activated sludge floc particles became increasingly more dispersed. In fact, the decreased COD removal at higher loadings was directly attributable to the increase in dispersed material found in the secondary effluent.

Comparison of the slopes of the curves in Figures 15 and 16 shows the beneficial effect of additional final settling time. At a net growth rate of 0.25 days $^{-1}$, and settling rate of 520 gpd/ft^2, the suspended solids removal is 93%; for the same growth rate and a final settling rate of 870 gpd/ft^2, the suspended solids removal is 90%. At a net growth rate of 0.50 days $^{-1}$, and a final settling rate of 520 gpd/ft^2, the suspended solids removal is 83%. For the same growth rate and a final settling rate of 870 gpd/ft^2, the suspended solids removal is 77%. Thus, the suspended solids removal at higher growth rates is aided by providing more final sedimentation time.

FIGURE 15
SUSPENDED SOLIDS REMOVAL FOR
FINAL SETTLING RATE OF 520 gpd/ft²

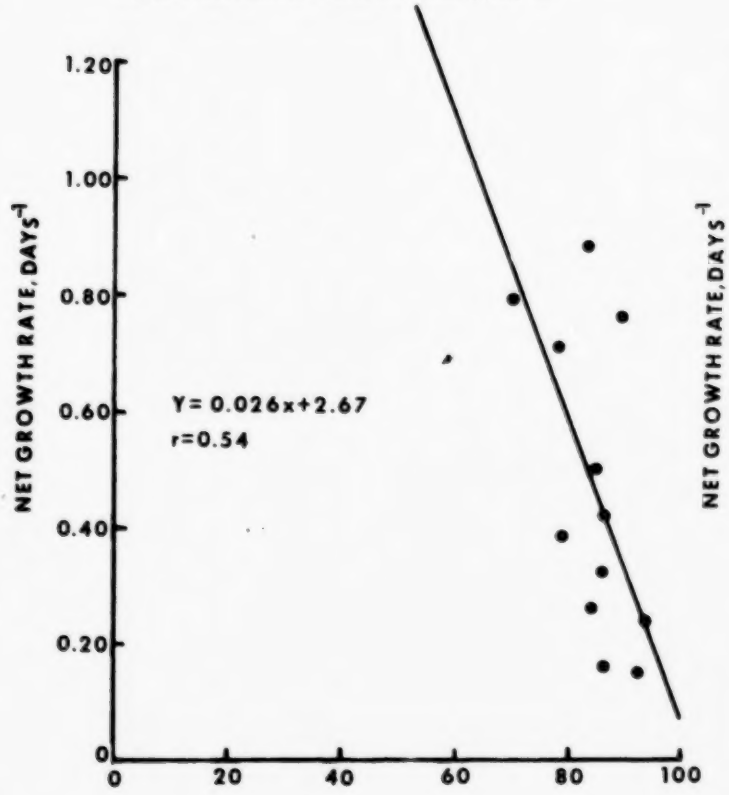
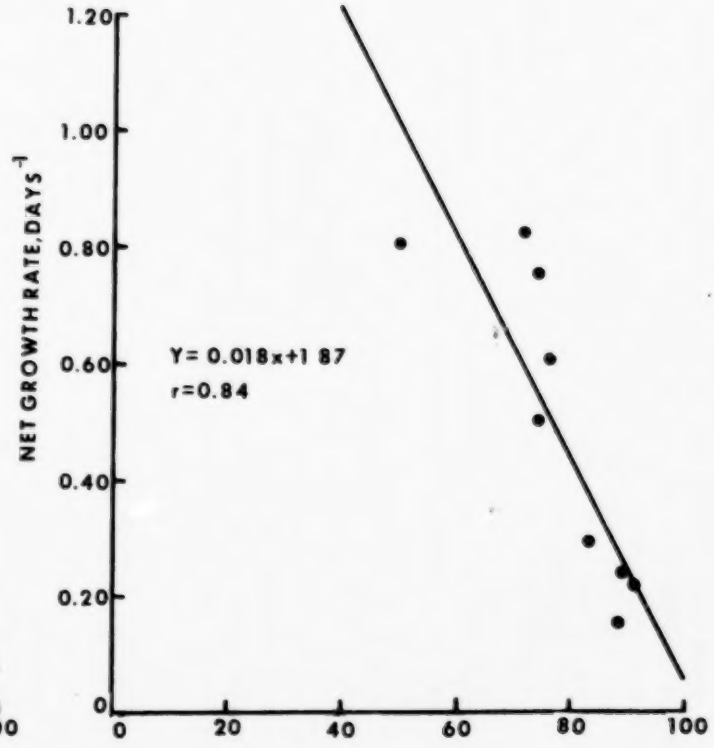


FIGURE 16
SUSPENDED SOLIDS REMOVAL FOR
FINAL SETTLING RATE OF 870 gpd/ft²



% OF INFLUENT SUSPENDED SOLIDS REMOVED

FIGURE 17
SUSPENDED SOLIDS REMOVAL FOR
FINAL SETTLING OVERFLOW RATE OF 520 gpd/ft²

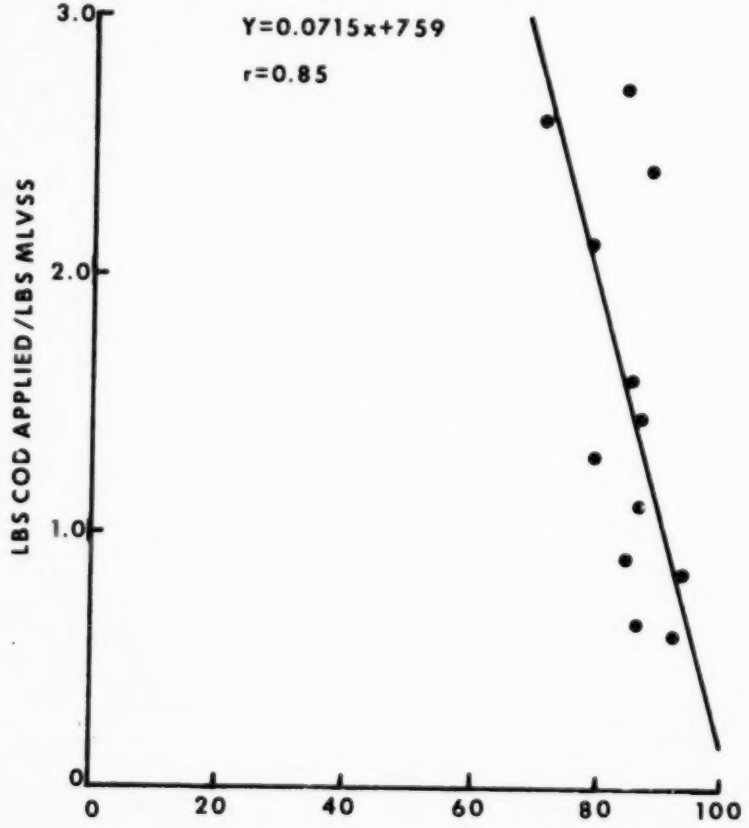
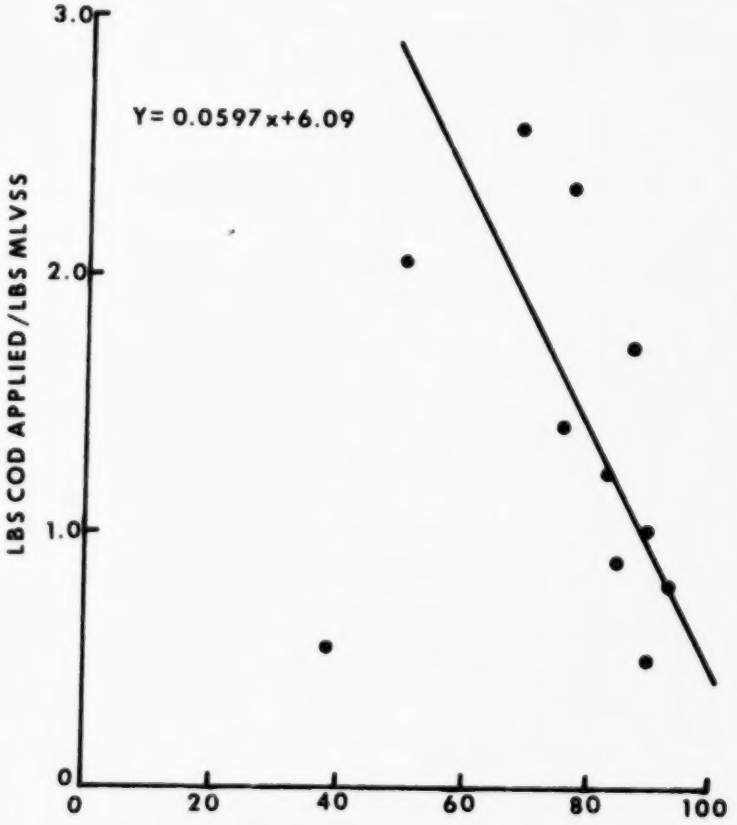


FIGURE 18
SUSPENDED SOLIDS REMOVAL FOR
FINAL SETTLING OVERFLOW RATE OF 870 gpd/ft²



% OF INFLUENT SUSPENDED SOLIDS REMOVED

The effects on net growth rate, substrate loading, and final settling rates on suspended solids removal were studied. A definite correlation was found to exist between net growth rate (or substrate loading) and suspended solids in secondary effluent as well as final settling hydraulic loading and quality of effluent.

Increased suspended solids will be found in secondary effluent at high growth rates due to the higher energy and resulting dispersive characteristics of the sludge floc.

At higher growth rates, some additional removal efficiency was gained from using final settling rates of 520 gal/ft^2/day over 820 gal/ft^2/day.

The efficiency of the final settler is shown as a function of COD loading in Figures 17 and 18.

VIII

NITROGEN REMOVAL

Throughout the contract study, attempts were made to study factors which contributed to the conversion of ammonia nitrogen to nitrate nitrogen. Nitrification is achieved by the action of certain autotrophic bacteria, "Nitrosomonas" and "Nitrobacter," utilizing ammonia and nitrite for an energy source, rather than carbonaceous compounds as do heterotrophic bacteria. The conversion of ammonia to nitrate is a two-stage conversion. First, the ammonia is converted to nitrite ion; second, the nitrite is converted to nitrate. The conversion of ammonia to nitrite takes place less rapidly than the conversion of nitrite to nitrate, thus, the seemingly instantaneous conversion of ammonia to nitrate. During the contract period, nitrification was never attained. The substrate loading rate was changed so frequently that the nitrifying organisms were not able to build up to the proper concentration. However, during the contract period, nitrification studies were being made in the west aeration tanks for a separate agency. The scope of the testing was not as great as the normal contract testing program, nor were the number of measurements as great. Some of the factors which affect nitrification were studied, and the findings are presented herein.

During the nitrification study, it was found that several factors influenced nitrification. They were: 1) net growth rate; 2) dissolved oxygen concentration; 3) detention time.

Operating conditions, which determine the net growth rate, also affect the rate at which nitrifying bacteria are built-up or lost in the process. The mass removal of nitrifying bacteria from the system will be proportional to the mass of solids removed in the waste stream. Thus, if the mass increase of nitrifiers in the aerator is greater than the mass lost in the waste activated sludge stream, the concentration of nitrifiers will increase, and nitrification will occur. The maximum production of nitrifiers is limited by the ammonia supply.

If a system is operated at a net growth rate exceeding the growth rate of nitrifying bacteria, nitrifiers will be wasted more rapidly than they can synthesize. To insure adequate nitrification, the net growth rate of the system must not exceed the net growth rate of the nitrifying organisms. In the west aeration battery tests, it was found that net growth rates in the range of 0.10 to 0.15 $days^{-1}$ enabled nitrification. Dissolved oxygen contents in excess of 2.0 mg/l were necessary to obtain nitrification. It was also found that long detention times were necessary, due to the minimal air supply available. Detention time used was 8.5 hours.

The total quantity of nitrogen removed in the activated sludge process may be calculated by mass balance. Table 5 shows mass balance values and total mass nitrogen removals.

TABLE 5

LBS/DAY

TEST	NH_3 in	KJN in	TOTAL N in	NH_3 Out WASTE	NH_3 Out EFFL	KJN Out WASTE	KJN Out EFFL	TOTAL N out
1	9082	3261	12343	117	6566	3222	2834	12739
3	8149	3723	11872	112	6688	3006	530	10336
5	7408	3621	11029	82	6139	2624	1364	10123
7	7298	3587	10885	111	4463	4573	5281	9854
9	7585	3771	11356	125	4100	4303	2014	10542
11	7575	3931	11506	145	5724	4062	1482	11413
13	7539	3931	11470	194	5728	3734	1392	11049
15	5580	4103	9683	127	3955	2846	1922	8850
17	6743	3783	10526	219	5020	3315	1621	10175
19	6003	3454	9457	179	4954	2676	1838	9647
21	6819	3511	10330	184	5236	3155	1825	10400
23	7374	3749	11123	107	5945	2481	1517	10050

An inspection of Table 5 shows that influent ammonia nitrogen is converted to Kjeldahl nitrogen. It is the opinion of the author that some of the influent ammonia was utilized in the formation of $MgNH_4PO_4$, a compound which plays an important role in phosphate removal. This nitrogen would show up in the form of Kjeldahl nitrogen in the waste sludge analyses.

Nitrogen removal was accomplished in the testing period by two mechanisms: 1) removal of nitrogen for cell synthesis 2) removal of nitrogen for $MgNH_4PO_4$ formation. The exact percentage removal of nitrogen attributable to each mechanism was not determinable, but could be inferred from the percentage required for phosphate removal.

Nitrogen removal was not accomplished with a great deal of success. Figures 19 and 20 show the percentage removals attained during each test. Substrate loading and net growth rate does not seem to affect the removal. The only effective method of nitrogen removal is nitrification and then denitrification. Unfortunately, nitrification was never established during the test period. Thus, a study of nitrogen removal was not possible.

FIGURE 19
RELATION OF SUBSTRATE LOADING AND NITROGEN REMOVAL

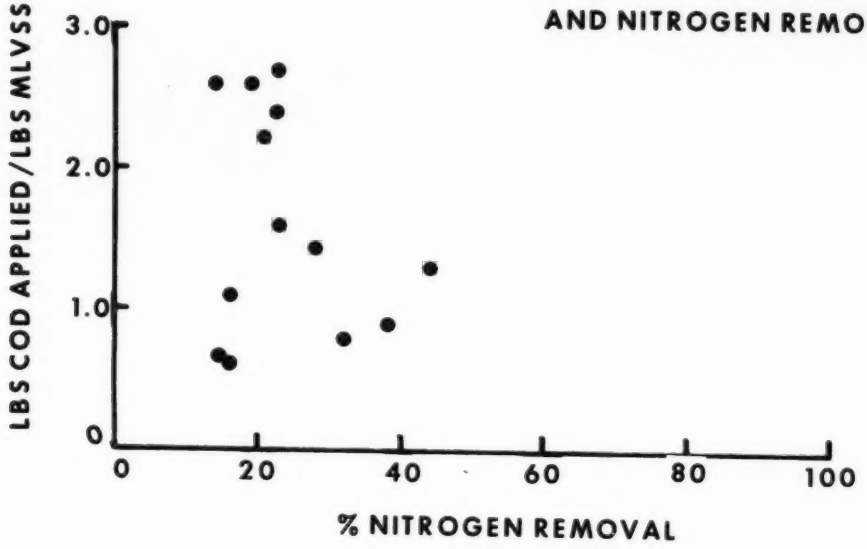
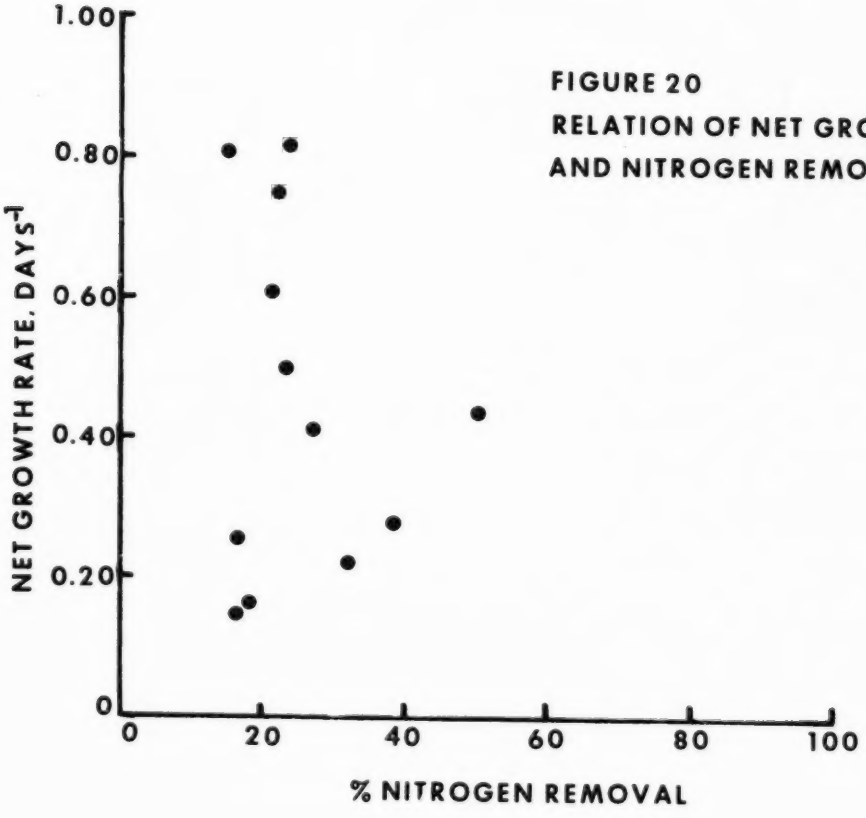


FIGURE 20
RELATION OF NET GROWTH RATE AND NITROGEN REMOVAL



IX

PHOSPHATE REMOVAL

It is an established fact that the activated sludge process has the capability of removing phosphorus from wastewater in varying quantities. This variable removal capacity, under many seemingly similar operating conditions, has led researchers into studies on the mechanism by which phosphorus is removed from wastewater.

If the actual mechanism which causes phosphate removal can be identified, then wastewater treatment plants may be designed and operated to take advantage of this mechanism if phosphorus removal is desired.

Among the possible methods of phosphate removal advanced are; chemical precipitation and biological uptake.

The postulated removal mechanism in the chemical precipitation theory is the increase of pH by the stripping of metabolically produced CO_2 in aeration with the subsequent formation of an insoluble chemical precipitate, chiefly a calcium phosphate compound. The insoluble phosphorus is then removed through the waste sludge system.

At Hyperion, under high rates of aeration, CO_2 was blown out of the mixed liquor and the pH was increased to a 7.5 to 7.9 range making conditions favorable for calcium phosphate precipitation. A good stoichiometric balance between phosphorus and calcium reduction in the effluent was obtained. However, subsequent work showed the reduction to be unique to Hyperion among the facilities in the Los Angeles area and indicated that the sludge cells themselves were in some way involved.

The dissolved oxygen content of the mixed liquor is not directly related to the precipitation of calcium phosphate. Rather, a high D.O. is linked to a high rate of aeration.

The postulated removal mechanism in biological uptake is a biological culture which absorbs phosphates in excess of that amount needed for cell synthesis.

In order for biological uptake to occur, Vacker, Connell and Wells[8] stated that the following operating conditions must be met:

1. D.O. greater than 2.0
2. MLSS approximately 1000 mg/l

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3. Substrate loading on the activated sludge between about 0.5 lbs BOD/lbs MLSS

4. No nitrification taking place

Throughout the testing period, phosphate levels were measured and recorded on 24-hour composite samples. Figure 21 shows the phosphorus removal resulting from each test. Inspection of the graph will show that phosphorus removal is not easily correlated to biological loading. If phosphate removal is achieved through biological uptake, high removals should have been obtained in the range of biological loadings from 1.0 to 1.5 lbs COD/lbs MLVSS. The majority of the high phosphorus removals did occur in this range. However, some low removals also occurred in this range of loadings.

Figure 22 shows the net growth rate of the process for each test with corresponding phosphate removals. Once again, it is evident that the level of biological activity alone is not the mechanism responsible for phosphate removal.

Figure 24 shows the relation between D.O. concentration and phosphate removal. Tests in which the lower percentage removals were reported, generally had higher D.O. concentrations, whereas, most of the high removals were obtained with the lower dissolved concentrations. Although, in all tests, the average D.O. was greater than 2.0 mg/l, it does not necessarily follow that phosphate removal is directly related to dissolved oxygen level.

Figure 23 shows the relation between the volatile percentage of the mixed liquor and the percentage of phosphorus contained in the activated sludge. Figure 25 shows the relation between the percentage removal of phosphorus and the volatile percentage of the activated sludge. An inspection of both graphs will show that greater phosphate removals were achieved at lower mixed-liquor volatiles, and that the phosphorus content of the sludge increases with decreasing volatile suspended solids. Taking both factors into consideration, it may be concluded that the decrease in volatile suspended solids is due to an increase in insoluble phosphate compound.

Thus far, it has been shown that:

1. Phosphate removal is not directly related to substrate loading.

2. Phosphate removal is not related to sludge growth rate.

3. D.O. alone is not a valid index to phosphate removal.

4. Phosphorus removed is contained in the activated sludge in an insoluble form.

FIGURE 21

SUBSTRATE LOADING vs PHOSPHATE REMOVAL

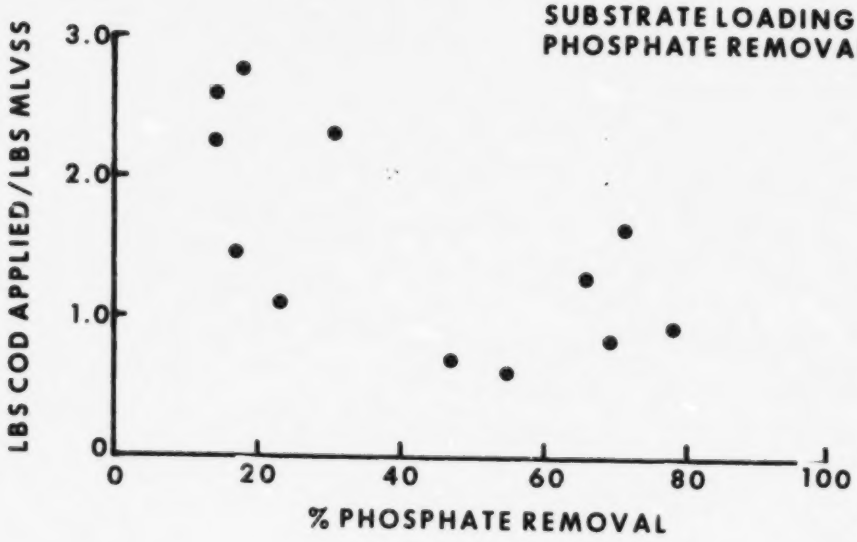


FIGURE 22

NET GROWTH RATE vs PHOSPHATE REMOVAL

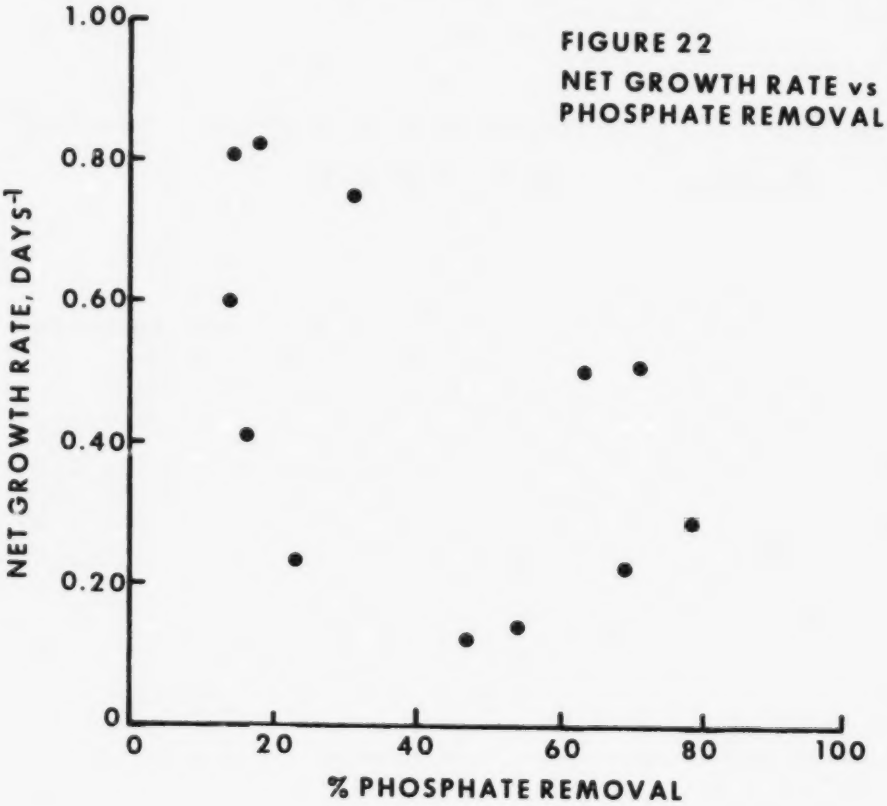


FIGURE 23
RELATION OF % VOLATILES AND PHOSPHORUS CONTENT OF ACTIVATED SLUDGE

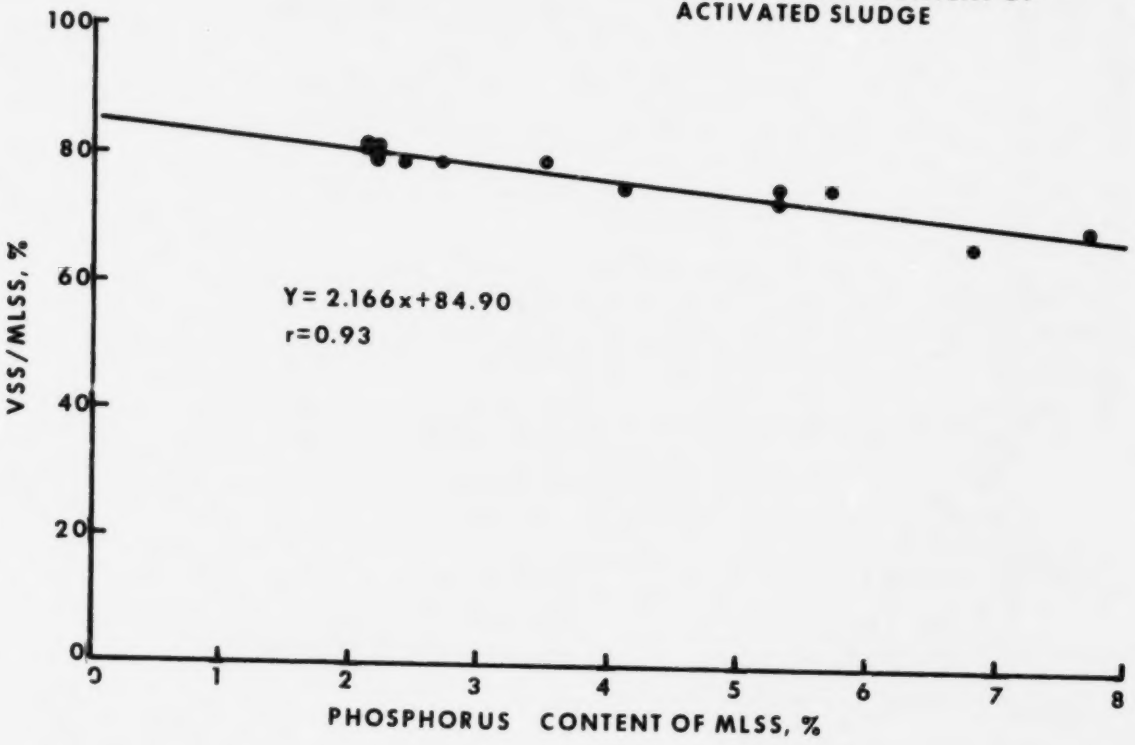


FIGURE 24
RELATION OF DISSOLVED OXYGEN IN ACTIVATED SLUDGE TO PHOSPHORUS REMOVAL

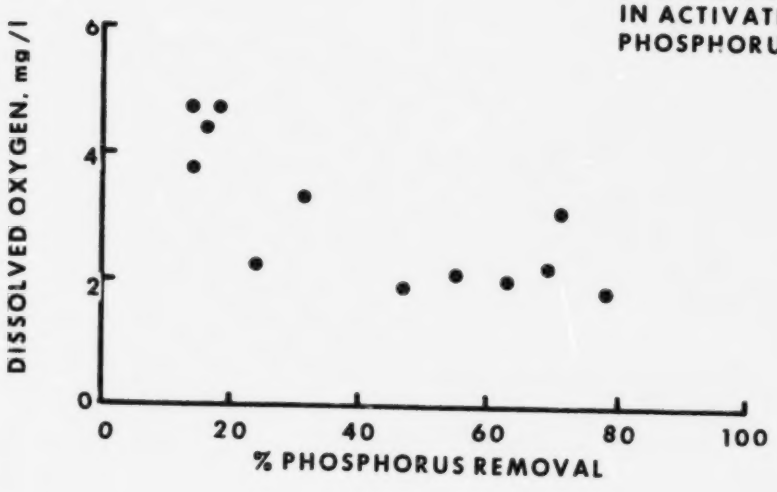
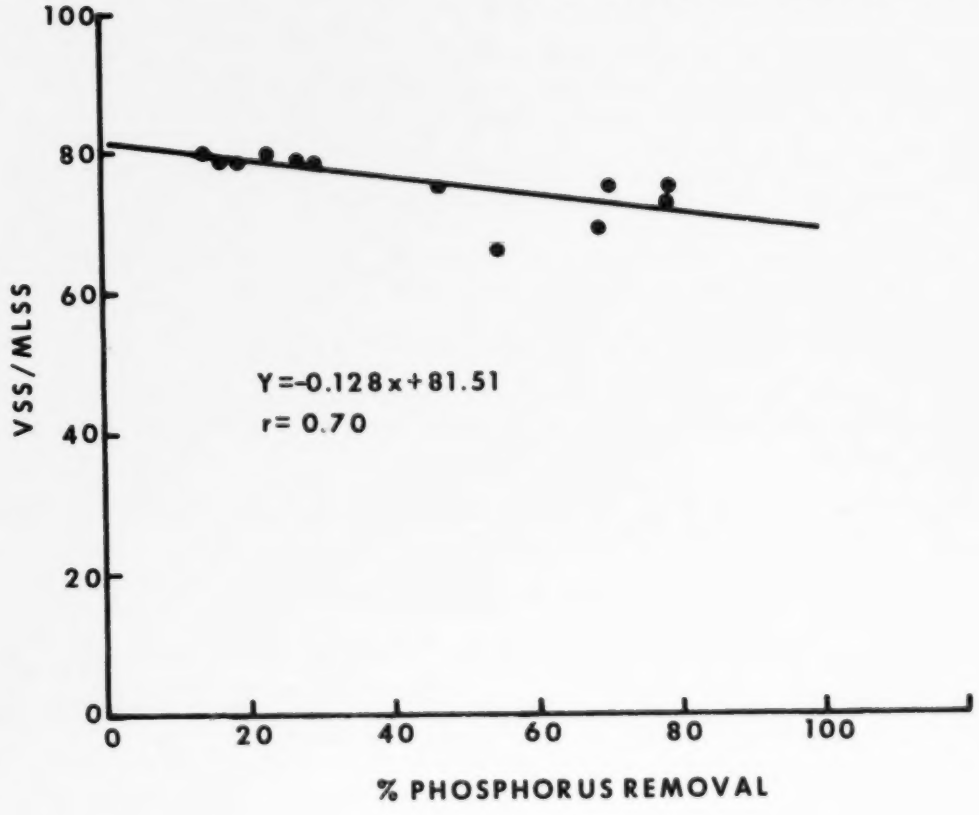


FIGURE 25

RELATION OF VOLATILE MATTER IN SLUDGE TO PHOSPHORUS REMOVAL



During separate experiments performed on the west aeration tanks, high phosphate removal was achieved. The original purpose of these experiments was to gather data on nitrification. However, it was discovered that phosphate removal was obtained at the same time.

During the period of operation from September, 1968, to June 1969, monthly removal of phosphate was in excess of that required for cell synthesis. Monthly removals were as follows:

MONTH	% PHOSPHATE REMOVAL
September	83
October	86
November	75)
December	75)
January	75) Estimated
February	75)
March	75)
April	95
May	96
June	96

Operation throughout this period was characterized by the following operational conditions:

1. High rates of air application
   1.40 ft^3/gal - September and October 1968
   1.80 ft^3/gal - November 1968 to July 1969

2. Long detention times (8.5 to 9.0 hours) in relatively long, narrow (plug-flow type) aeration basins

3. Low solids loadings, (0.50 lbs COD/lbs MLVSS) producing a well settling flocculating sludge

4. pH of activated sludge mixed liquor measured 7.6 on the average

5. During April, May, and June when phosphate removals averaged 96%, the waste activated sludge was not returned to the primary tanks.

Operation of the east aeration tank battery was characterized by the following conditions:

1. High air supply rates, 1.4 to 1.6 ft^3/gal

2. Lower detention times, 4.5 to 6.5 hours (See Table 2)

3. Tests in which phosphate removal was poor were characterized by a dispersed, nonflocculating sludge mass.

4. pH during all tests was high, between 7.5 and 7.8

It seems that the phosphorus is removed by some other mechanism than biological activity. This is shown by the large scatter of data on Figure 21.

A stoichiometric balance between calcium and phosphorus reduction in the effluent with the fact that volatiles decrease at times of high removal indicated that chemical precipitation is occurring. The fact that only the Hyperion sludge of the facilities in the Los Angeles area is capable of removing phosphorus, although other physical operating parameters were the same, indicates the sludge organisms themselves may also be involved.

It has been postulated that phosphate removal is accomplished by the formation of a calcium phosphate precipitate. In order to form this precipitate, the following conditions are required.

1. Calcium and phosphate in high enough concentrations to form an insoluble precipitate.

   Jenkins and Menar[9] have shown that activated sludge organisms require from 2% to 3% of their weight in phosphorus for cell synthesis. Sawyer[1] has found that domestic sewage has phosphorus concentrations far in excess of that needed for cell synthesis. The sewer system of the City of Los Angeles services hard water areas. Analyses have shown calcium ion concentrations averaging 62 mg/l.

2. Calcium and phosphate ions in free form.

   In sewage, calcium and phosphate ions are not always in their ionic forms, readily available for precipitation. Phosphorus may occur as complex inorganic phosphates, such as polyphosphates and pyrophosphates. It also may appear in the form of complex organic phosphates. The final form of phosphorus in the phosphorus cycle is the phosphate ion (PO_4^{-3}). However, during the treatment process, most of the organic and some of the complex inorganic phosphorus compounds are hydrolyzed or decomposed to the inorganic phosphate ion. Calcium is also found in many forms other than the free iron. It is frequently tied up with the fatty acid anions, or in dissolved calcium complexes. These complex compounds will also be broken down in treatment, releasing more of the free calcium ion.

   Although it may appear from a chemical analysis that there is an abundance of calcium and phosphate for precipitation in raw sewage, the fact is that there may be insufficient quantities of the free ions for precipitation before the aeration process.

3. Proper conditions for the formation of a precipitate.

Work by Jenkins and Menar[9] has shown that the solubility product of calcium phosphate decreases with increasing pH. Throughout the Federal Contract testing, a pH rise of 0.3 to 0.4 was noted. In a plug flow situation, the greatest biological activity (and thus the greatest CO_2 production) will occur at the inlet end of the aeration tank. The agitation of the applied air will tend to strip the mixed liquor of its CO_2 content, and thus raise the pH. This stripping action would naturally be more effective in the portion of the tank where CO_2 production is lowest. Thus, towards the outlet end of the aeration tank, the pH will rise. The rate of aeration will govern the quantity of CO_2 removed from solution.

Also, in a plug flow type of aeration tank, adequate time is given for the breakdown of the complex phosphate and calcium compounds. In a completely mixed aeration tank, some of the incoming flow leaves the tank immediately. This condition is not conducive to complete hydrolysis of all complex organics or to CO_2 stripping.

High phosphate removals were achieved in Test 1, 3, 5, 7, 9, and 11.

Table 6 shows the pertinent removal data.

TABLE 6

TEST	AIR RATE ft^3/gal	pH	DETENTION TIME HOURS	% VOL.	% P	% REM.
1	1.40	7.5	6.5	69	7.6	69
3	1.40	7.3	6.5	66	6.2	55
5	1.40	7.4	5.5	75	3.8	47
7	1.56	7.5	4.5	73	5.0	78
9	1.56	7.5	4.5	75	4.7	63
11	1.52	---	4.5	75	5.1	71
13	1.52	---	4.5	79	2.6	31
15	1.60	7.6	6.5	79	1.3	17
17	1.60	7.7	6.5	73	1.3	18
19	1.60	7.7	6.5	78	0.7	14
21	1.60	7.7	6.5	80	1.0	14
23	1.60	7.5	6.5	80	1.5	24

Tests 1, 3, 5, 7, 9, and 11 were characterized by high air rates, sufficient detention times, high mixed liquor pH, and low mixed liquor volatiles. However, there are contradictions in the data. Poor phosphate removal was achieved during Tests 13, 15, 17, 19, 21, and 23. These tests were also characterized by high air rates, high pH, and

reasonably long detention times. One factor may be responsible for poor removal. The substrate loading during these tests was high (see Table 1) and the resultant floc was rather disperse.

Jenkins and Menar[9] have postulated that the phosphate precipitate is in a colloidal form. If an activated sludge is well flocculated it is feasible that considerable quantities of colloidal precipitate would not be picked up by the sludge mass and would pass off in the secondary effluent. The colloidal matter would not be trapped on the filters used for analysis of total and soluble phosphates in secondary effluent either, and would show up in analysis for soluble phosphates.

Test 24 was terminated in the middle of April 1969. It should be noted that sewage temperatures were rising, and that the substrate loading had approached a more conventional value, resulting in a better flocculating sludge mass. Phosphorus removals were also higher than in previous tests.

In the previous discussion, it has been postulated that a cation combines with phosphate ion to form an insoluble precipitate. Jenkins and Menar[9] have proposed that the cation involved is calcium ion. However, past operational experience at Hyperion has shown that the cation involved in the precipitation reaction possibly is not calcium, but a magnesium ammonium complex. A review of past operational history will demonstrate the reasoning for the above statement.

Both the digested sludge and waste sludge lines at Hyperion have been found to have a hard crystalline coating on the pipe interior at bends, venturi tubes, contractions, and expansions. This hard crystalline coating was analyzed and found to be magnesium ammonium phosphate ($MgNH_4PO_4$). In the waste sludge line, this coating has been found in the line at venturi tubes. It is possible that the flow turbulence present at these points allows for some release of CO_2 and pH drop occurs, enough to cause accumulation of $MgNH_4PO_4$ in the pipeline.

Based on mass balance calculations, dissolved phosphorus appears to be converted to particulate phosphorus within the process and nonvolatile suspended solids appear to originate with the process. The retio of nonvolatile mass generated within the process to dissolved phosphorus converted to particulate within the process might give a clue to the species of the salt formed. The average of mass of salt formed to mass of phosphorus in the salt = 4.72. The ratio of total mass to phosphorus fraction for $MgNH_4PO_4$ is 4.4, which is identical to the ratio for $(Ca)_3(PO_4)_2$.

In light of the foregoing discussion, it has been found that phosphate removal will occur at Hyperion if certain physical and chemical conditions are met. These conditions are:

1. Proper aeration basin design

   For effective phosphate removal, complete hydrolysis of complex calcium, magnesium and phosphate compounds must occur. Two conditions are necessary to achieve this goal; long detention times and plug flow type aeration basins.

   A plug flow type aeration basin will enhance distribution of oxygen demand, making conditions at the outlet end of the tank conducive to carbon dioxide release.

2. Operational mode

   To insure capture of colloidal phosphate particles in the floc, the activated sludge process should be operated in a mode which provides a well flocculated sludge. From data in Table 2, organic loadings up to 1.5 lbs. COD applied/lb MLVSS provided good flocculation.

Work at other facilities in the Los Angeles area indicated that achievement of these characteristics would not necessarily result in phosphorous removal. Hyperion sludge would remove phosphorous from these wastewaters while their sludge would not remove phosphorous from Hyperion wastewaters. Some sludge mechanism may therefore be present.

Phosphate removal has been accomplished at Hyperion through a possible chemical precipitation. Many operating factors have been defined which are conducive to phosphate precipitation. However, some facets of the reaction appear to be characteristic of Hyperion sludge only. A study of this atypical reaction is necessary.

X

EXPERIMENTAL RESULTS - PHASE II

The purpose of Phase II was to gain information on the removal characteristics of the activated sludge process when treating a diurnal flow. All previous tests had been run on a system treating a steady flow.

The flow stream into the east secondary treatment unit was varied according to the pattern listed in Table 3. Air rates were established according to the pattern listed in Table 4. It should be stated here that the use of low air rates at points of maximum substrate loading was a limitation inherent in plant facilities, and not planned for the testing.

The time-dependent removal characteristics are shown in Figures 26, 27, 28 and 29. An inspection of Figure 26 shows the extreme variations in influent COD to be damped out to a considerable extent. The same effect is observed in Figure 28, showing nitrogen removals. In Figure 29, no correlation of phosphate removals may be obtained.

In general, the results of the time-dependent tests were not too reliable. The lack of reliability can be attributed to two factors. They are:

1. Unstable operating conditions

   The lack of sufficient quantities of air during peak loading periods, and the inability to waste in conjunction with periods at peak waste sludge production did not enhance the attempt to develop steady-state conditions.

2. Difficulty with the Auto-Analyzer

   Many operating difficulties plagued the use of the auto-analysis equipment. Little time was available for familiarization with the units as delivery was eight months late. It was fortuitous that a time extension of the contract was granted, because delivery was not accomplished until after the original contract expiration date. Complete maintenance manuals did not accompany the delivery of the instrument. These were requested in May, but were never received. The automatic sampling programmer was found wired incorrectly, but this was repaired by Hyperion personnel.

   The instruments were set up in shelters immediately adjacent to the aeration tanks and final settling tanks.

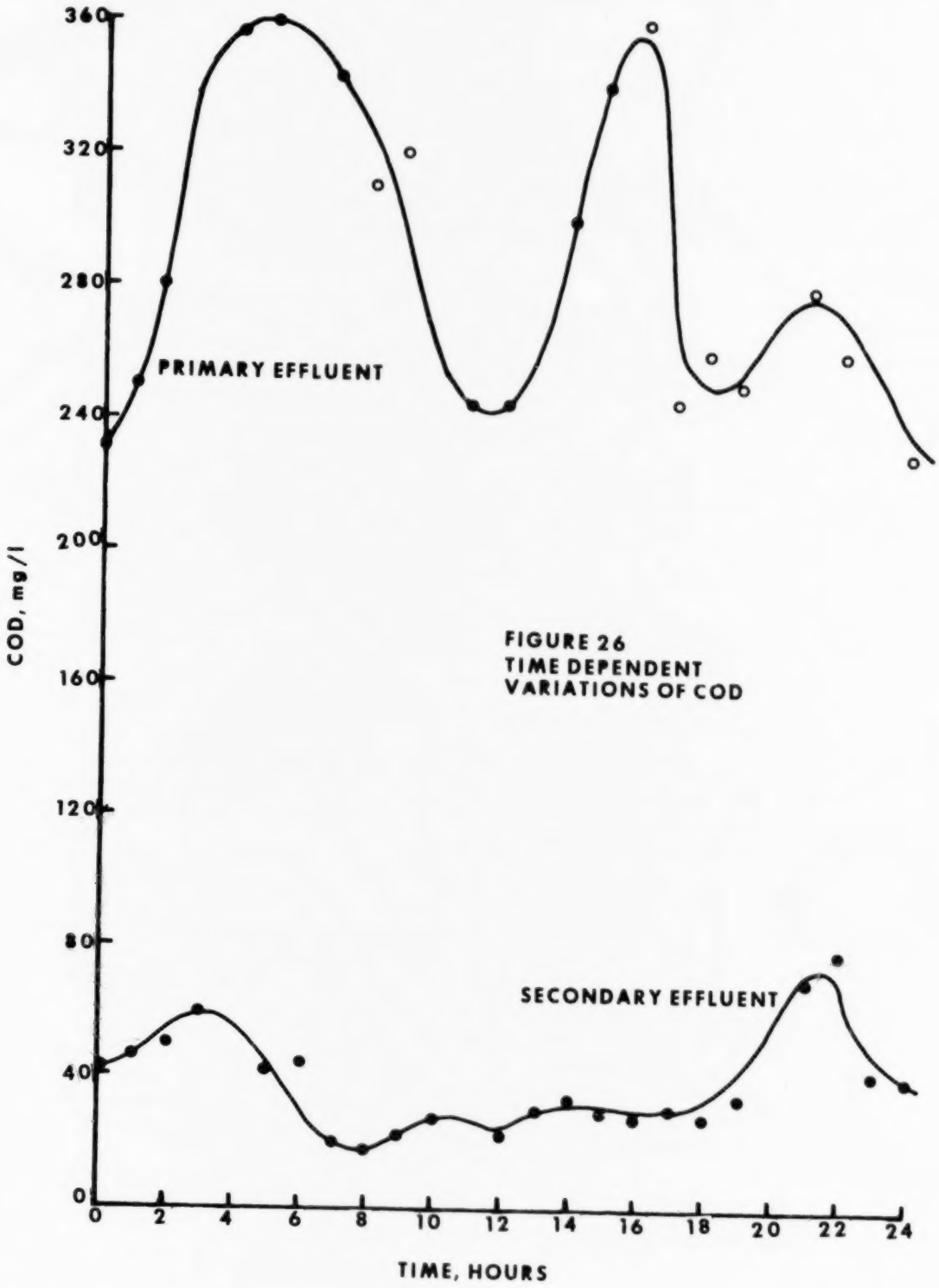
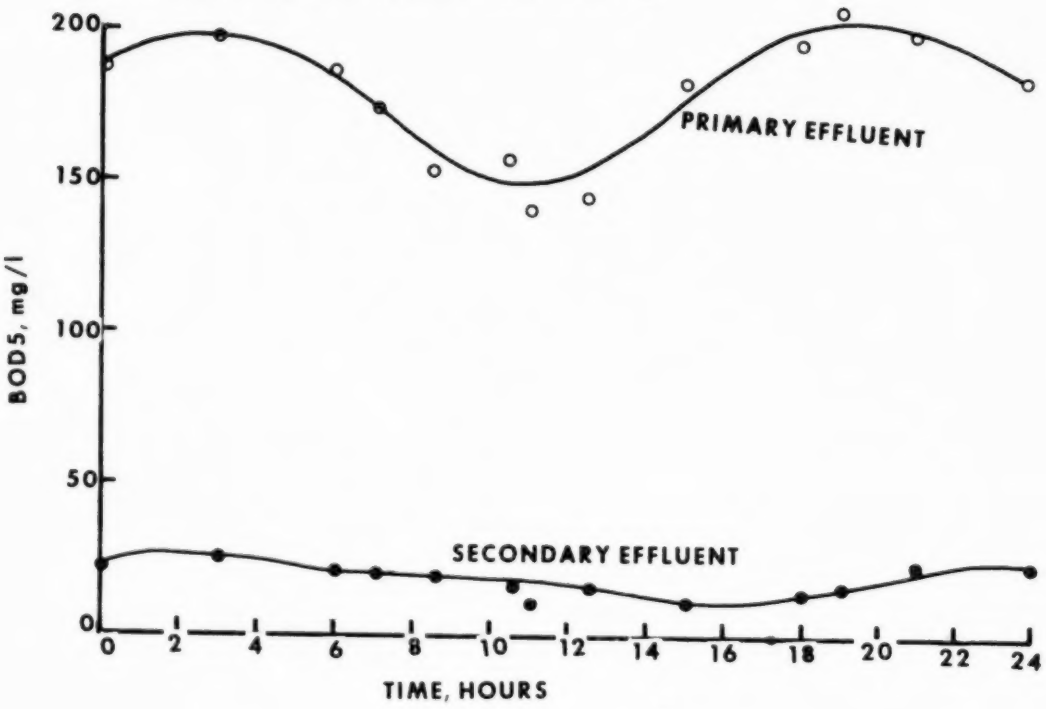


FIGURE 26
TIME DEPENDENT
VARIATIONS OF COD

FIGURE 27
TIME DEPENDENT VARIATIONS OF BOD_5



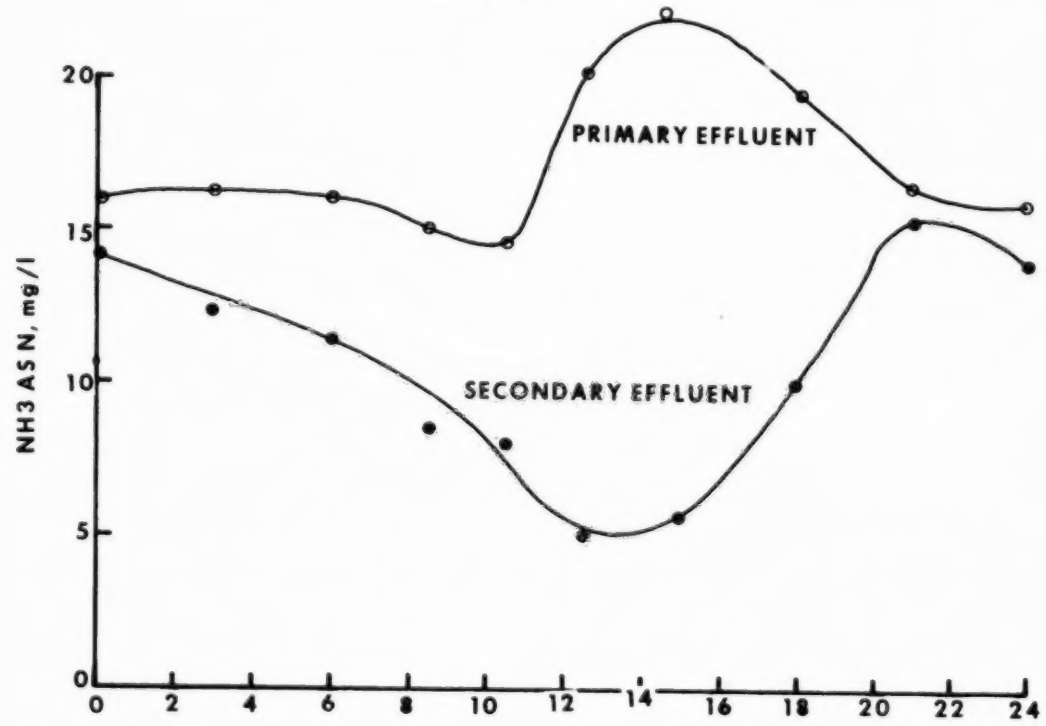


FIGURE 28
TIME DEPENDENT VARIATIONS OF AMMONIA

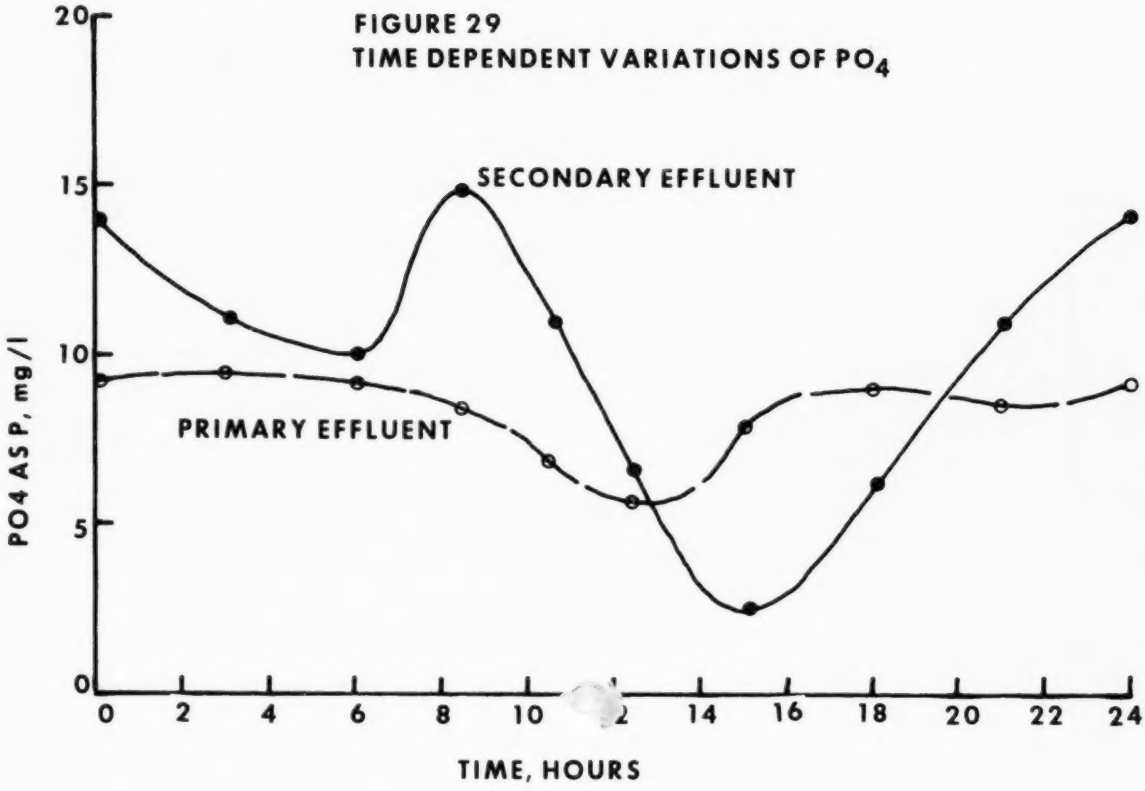


FIGURE 29
TIME DEPENDENT VARIATIONS OF PO_4

One month was available for shake-down and familiarization with the equipment. Standardization began in June 1969. The following paragraphs demonstrate the problems involved in use of the automatic analysis equipment.

Equipment Start-up and Standardization

June 12-13, 1969

The COD test was extremely difficult to stablize. Light transmission was inadequate, and air bubbles formed in the flow cell.

In the nitrate tests, zinc reduction was used to avoid handling hydrazine, a highly reactive reducing agent. The system was quite noisy.

Precipitation occurred in the tubing during the ammonia tests, causing poor standardization.

Difficulties encountered in the phosphate testing were a gradual precipitate formation in the tubing, and excessive color in the product stream.

Since the sampling lines are rather long, switching of samples required too much time to allow for purging of the sample from the previous cycle. Pumps were used to obtain continuous flows from all sampling points, with arrangements for periodic testing from those streams.

Glass wool ahead of the flow cell was used to filter out suspended matter and another exit line to the pump was put in for continuous precipitate removal.

June 16-20, 1969

The COD colorimetry was very unstable, and had poor sensitivity. Special small apertures were drilled for a reference side to match the low output to the sample side. The colorimeter was completely realigned, but it still had a baseline drift due to bubbles in the tubing. The highly viscous sulfuric acid solution will not permit bubbles to be rejected. Acidflex tubing has poor elasticity so that tubing "snaked" to affect pumping rates. The heating bath thermostat burnt out; but was replaced. The final effluent line became plugged with algae.

The nitrate and ammonia tests required realignment of the colorimeters. The chart speeds were changed from 18"/hr to 2"/hr to facilitate reading chart, because red pen leaked excessively at slower chart speed.

June 23, 1969

The nitrate system was changed from zinc reduction to hydrazine sulfate reduction due to chronic plugging at the zinc column and the unpredictable efficiency of reduction. Hydrazine sulfate is a liquid reducing agent but had to be handled carefully in concentrated form. The nitrate system had 20-minute response time from entry to recording.

Suspended solids from the aerator effluent plugged the valve in the sample programmer unit, requiring back flushing. Frequent visual checks of flow pattern were necessary to insure free flow.

June 30 and July 1, 1969

The COD test became unstable due to the colorimeter slipping out of alignment. Realignment corrected the problem but shifts occurred frequently.

On-Line Testing

July 2-3, 1969

The COD test was usable with frequent standardization. It worked well for a six-hour period, until a leak developed at the heating bath connection. COD reagents were replenished, causing baseline shifts that were improperly adjusted by inexperienced operator.

The ammonia and phosphate tests worked well for a 12-hour period except for a recording pen leak and some zero shift in the ammonia system.

After an overnight shutdown, the nitrate system became unstable. Consequently, one reading every two hours was obtained.

July 8-10, 1969

In the phosphate and ammonia tests, increased aeration caused some problems in keeping the sampling line submerged. The line to the mixed liquor separated and fell into the primary tank and was not detected for one and one-half days when primary and mixed liquor results were suspiciously alike. With the line repaired, there was ten hours of good data.

The ammonia system became erratic due to precipitate accumulation.

The nitrate test was satisfactory except for some fluctuation at low nitrate values.

The COD test was usable with frequent standardization.

The results of analyses for time dependent characteristics of the activated sludge process showed interesting, but not conclusive trends. The ability of the activated sludge process to minimize variations in influent streams was demonstrated, but equipment failure, poor operating conditions and lack of time prevented an in-dept analysis.

The activated sludge process is able to minimize variations in the influent stream. Quantitative values of the maximum and minimum variations obtainable under different operational modes was not possible due to the limited time available for testing.

XI

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